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Promoting Chemistry Learning through Undergraduate Work Experience in the Chemistry Lab: A Practical Approach

Hong-Bin Yu*,†,‡

†Department of Physical Sciences, Wagner College, Staten Island, New York 10301, United States

‡Department of Chemistry, College of Staten Island, The City University of New York, Staten Island, New York 10314, United States

ABSTRACT: Hiring undergraduate lab assistants in chemistry departments is common in college. However, few studies have focused on promoting undergraduate chemistry learning and thinking skills through this work experience in chemistry teaching laboratories. This article discusses the strategy we implemented in the lab assistant program. The student-centered, inquiry-based work experience provided a unique learning environment for undergraduate students. A routine lab assistant job can be transformed into a unique chemistry learning experience. The development of critical thinking skills, problem solving skills, and working skills from this job experience promotes undergraduate learning and shapes students' future study.

KEYWORDS: *General Public, Inquiry-Based/Discovery Learning, Problem Solving/Decision Making, Student-Centered Learning, Laboratory Management, First-Year Undergraduate/General, Second-Year Undergraduate, Upper-Division Undergraduate*

INTRODUCTION

The majority of chemical education research has focused on developing undergraduate curricula, including lectures and laboratories, on instructional strategies and assessment.[1] A great amount of research has also been performed to improve chemistry learning experiences beyond the classroom, including undergraduate research,[2] learning communities,[3] and learning chemistry in informal environments.[4] Recently, curriculum-based service learning has been shown to improve course-related skills and the application of the course concepts to the real world.[5] However, promoting chemistry learning through undergraduate work experience in chemistry laboratories has not been explored extensively.

Hiring undergraduate lab assistants to help the lab staff in teaching laboratories is not uncommon in colleges, especially in departments where the lab personnel resources are limited. Lab assistants get paid through government financial aid programs such as work-study or through the department budget. Students who participate in the program benefit from this job experience in their current college learning and future career development. Usually under the supervision of the lab staff, the lab assistant's routine jobs include performing laboratory upkeep such as cleaning laboratories before and after the lab sections, dispensing supplies into the laboratory, washing glassware, and stocking supplies. Lab assistants are usually told exactly what to do on the job. We envisioned that if lab assistants were given more challenging tasks through inquiry based assignments[6] in addition to the routine lab upkeep, their jobs could be expanded to planning, organizing, and decision-making in lab preparation, trials of new lab exercises, and routine instrument maintenance. Each year, 5 or 6 out of about 150 students who are taking science courses at Wagner College are hired as lab assistants in the department. Although this is a small group of students, this job opportunity still can be used as a teaching tool to enhance student chemistry learning and to improve problem-solving skills. This article presents how we have implemented inquiry-based job assignments in lab assistant routine tasks to promote student learning and thinking skills. A survey also showed positive feedback from the students on how the work experience influenced their academic study and future career.

IMPLEMENTATION OF CHEMISTRY LEARNING IN UNDERGRADUATE LAB ASSISTANT WORK

Inquiry-based teaching has been widely applied in lecture and lab course chemistry education.[7−9] It combines hands-on activities with student-centered discussion and discovery of concepts. We envisioned that if an inquiry pedagogy is woven into the student lab work assignments, it could become a great opportunity for undergraduate students to enhance their chemistry learning, their problem solving skills, and critical thinking skills.

In order to lead students into this active learning environment, three periods of training are facilitated at the beginning of the fall semester and then throughout the school year. In the first 2 weeks of the fall semester, lab assistants rotate their jobs in all the teaching laboratories and stockrooms in the department. Their main jobs in this period are routine lab upkeep, such as cleaning, stocking, and dispensing the chemicals and supplies to the laboratories under the supervision by the lab coordinator. The purpose of this period of work is to have lab assistants become familiar with their work environment and understand the safety procedures of their job. In the second period, lab assistants are assigned to watch the chemical preparation demonstration that is performed by the lab coordinator. During this period, lab assistants focus on techniques and safety protocols involved in the preparations. All calculations and procedures are provided. The lab coordinator explains the protocol and key issues that are involved in the particular procedure. During the demonstration, lab assistants are also asked to assist the preparation, such as finding the right apparatus and supplies and preparing bottle

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labels. The techniques they learn in the demonstration are transferring solid and liquid chemicals, weighing solid chemicals, measuring liquid samples, using a Bunsen burner, preparing aqueous solution from solid samples, preparing aqueous solution by dilution and titration, and setting up demonstration apparatus for the upcoming lab sections. After the first few weeks of training, our student lab assistants are familiar with their job routine, their work environment, and their job responsibility in the department. They have also learned the techniques that are involved in the lab preparation. Then in the last period, they are assigned open-ended and student-centered tasks.

In this final period, when the lab assistants report to the job, they are given a list of work tasks. Instead of being told exactly what to do, they are given the opportunity to evaluate their task and discuss their plan with the lab coordinator. With the list of work tasks, a set of questions are given to lab assistants to think about before they start.

1. What are the jobs?
2. How long will you work today?
3. How are you going to manage your time to finish the job on time?
4. What are the chemicals you will handle today? Do you know their physical and chemical properties and how to safely handle these chemicals?
5. If there is a preparation today, do you understand the chemistry behind the preparation? Provide your calculation and detailed procedure.

These inquires allow students to examine the task on their own and offer them the freedom to structure their time and channel their energy to the tasks. To seek the answer, students think critically on how to manage their time, analyze the situation, and finish the task efficiently. In the meantime, they learn how to apply chemistry knowledge they learned from their classes to accomplish the job assignment. These tasks could be as small as putting glassware away or as serious as preparing solutions for 120 students. Instead of simply following directions, lab assistants learn to become decision makers by practicing how to analyze tasks, seek directions, and meet expectations during their work.

The following are two common cases that involve inquiry-based job assignment.

Case 1: A Routine Inquiry-Based Job Assignment

Two lab assistants come in for 1.5 h of work.

Job 1: One laboratory needs to be cleaned and then a new experiment needs to be set up for afternoon new lab sections.

Old experiment chemicals and apparatus in the classroom: vitamin C tablet (50 count), ascorbic acid (4 bottles of 100 g), potassium iodide (4 bottles of 200 g), iodine (4 bottles of 100 g), 100 mL volumetric flask (14 count), mortar and pestle set (14 count), buret and stands (14 sets), waste bottles.

New experiment chemicals and apparatus being put out in class: 0.130 M $KMnO_4$ (2 bottles of 500 mL), 0.755 M $H_2C_2O_4$ (2 bottles of 1 L), buret and buret stands (14 set up), 1 box of 15 × 120 mm test tube, medium test tube rack (14 sets), waste bottles.

These are the chemicals and apparatus provided in classroom for students. Other necessary glassware and apparatus are available from students' individual lockers.

Job 2: Prepare 500.0 mL of 0.130 M $KMnO_4$ aqueous solution for the next day's lab sections. This preparation has to be done by both lab assistants working together.

This is a multitask job that requires two lab assistants cooperating with each other to accomplish the task in a timely fashion. In our daily teaching lab routine, multiple laboratories are usually running at the same time. When lab assistants report to their job, they are usually assigned different tasks according to their availability and job load of the day. An easy job such as organizing and cleaning is assigned to one student. Challenging jobs such as preparing chemical reagents and materials are assigned to two or more students. Multitask jobs like this one could be overwhelming to new lab assistants. To ease their anxiety and help them to be familiar with the job routine, they are paired with an experienced lab assistant in their first multitask job if their work schedule fits.

Instead of simply telling the lab assistants what to do at the start, the lab coordinator gives them the list of jobs and tells them what is expected. Lab assistants are given time to discuss with the lab coordinator, or with each other, their work plan. To stimulate their thinking, the lab coordinator reminds them to think about the five questions that are listed above. In this case, job 1 involves handling a number of chemicals and apparatus. Some chemicals need to be returned to the stockroom location; some chemicals need to be placed in the classroom; and some apparatus needs to be washed and dried. In order to have the lab organized on time, they need to think about how to play their roles in the team and how to manage their time and energy during this work. In job 2, a preparation of aqueous solution is involved. Lab assistants are expected to use the chemistry concepts including moles and molarity they learned in the chemistry lecture while preparing the solution. In the meantime, lab assistants are expected to have adequate knowledge about properties of the chemicals and safety protocols while handling these chemicals. The discussion provides them the opportunity to evaluate the situation, understand the expectation and determine the work plan.

After the discussion, lab assistants plan to finish the two jobs as follows:

1. Clean and set up laboratories for the afternoon class (30 min): They work together to ensure reagents, gloves, waste bottles, and soap bottles are in place. One student will take care of the old experiment and remove all supplies and chemicals from the laboratory while the other student will be in charge of the new experiment. Then, they will wash the glassware together.

   Note: In some cases, if there are two laboratories that need to be cleaned, there are two options. They can either work together to finish the tasks, or each of them can be in charge of one lab. Interestingly, most of time, lab assistants will choose the first option. They prefer to help each other finish the job assignment on time as a team. It shows that team work makes them feel comfortable and more confident to finish the task.
2. Prepare the stock solution (60 min): One student will be in charge of the procedure, and the other will find the reagents and apparatus. They will cross check each other's work before they start the preparation.

   Note: The preparation procedure will be approved and monitored by the lab coordinator.

After their job plan has been approved by the lab coordinator, lab assistants set off to finish their tasks, clearly knowing what to do and how to do it.

During the first half hour, our two lab assistants manage to work together as they planned. In order to follow the safety

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J. Chem. Educ. XXXX, XXX, XXX−XXX

protocol while they handle the chemicals, lab assistants are required to read the chemical hazard and first aid procedures on "Right to Know" labels. This requirement is expected to increase their knowledge of the chemicals and physical properties of these chemicals beyond what is presented in textbooks. In the meantime, lab assistants learn how the manufacturer packs the chemicals properly and safely and how we store the chemicals properly to prolong the shelf life. In this case, they learned potassium iodide is light sensitive. The manufacturer packs the potassium iodide bottle in a sealed aluminum wrap. When we prepare the class bottle for the lab section, we store the potassium iodide solid in amber bottles to minimize the light exposure. Iodine sublimes easily and causes brown stains on the surrounding objects. Therefore, iodine containers have to be tightly closed at all times. Ascorbic acid is a white solid, but commercial Vitamin C has a unique attractive color. The color has nothing to do with the active ingredient in the tablet. Potassium permanganate is a strong oxidant and has a unique dark purple color. Potassium permanganate is originally purchased in pure solid form. The solution has to be freshly prepared and stored in a dark place to ensure accurate molarity. These are examples of the types of information that are not explicitly described in their chemistry textbook or lab manual but presented to them now at the lab job. Lab assistants gain this first-hand information from their work. While other students in class are just using the chemicals in their experiment, our lab assistants already have an in-depth knowledge about chemical and physical properties of the chemicals and their handling safety.[10] In their own lab classes, most of the time they are in the lead group and finish the experiment successfully and efficiently. Throughout the school year, there are more than 100 different chemicals involved in our chemistry laboratories. Lab assistants learn a little information at a time about these chemicals. Our survey results showed lab assistants feel that they are knowledgeable about the chemical and physical properties and how to handle these chemicals safely after the job experience. Lab assistants are provided a new environment to learn chemicals and their properties outside the classroom.

As planned, during the first half hour, after knowing the properties and safe handling of the chemicals, lab assistants work together to put away the chemicals and the apparatus of the old experiment. All chemicals are returned to their desired location in the preparation room. They also rinse the mortar and pestle sets, volumetric flasks, and burets. Then, they take out new chemicals and new apparatus for the next experiment in the laboratory. In the meantime, they check the laboratory to ensure there are enough gloves, soap bottles, and wash bottles in place.

During the next hour, the lab assistants help each other for the preparation work (job 2). Preparation of chemicals, such as stock solutions, is the most common job in the lab preparation. Depending on the lab assistants' year level, freshmen and sophomores are given tasks such as making aqueous solutions that actually serve as enrichment for their general chemistry courses; juniors and seniors are given tasks such as instrumental maintenance, as this expands their chemistry experience horizon.

Unlike in the demonstration where all calculations and procedures were provided to the lab assistants, at this stage, the preparation requires lab assistants to perform the calculations, write the experimental procedures, and then complete the preparations. Once the preparation task is chosen, lab assistants are asked to do the following:

- Calculations.
- Write the detailed procedure. Our lab assistants consider it a "super" detailed procedure. The following questions are usually presented for the lab assistants to take into consideration before they start writing the procedure: In what order should the preparation be performed? What apparatus will be used and at what size? What chemicals are used? What safety procedures should be followed?
- Revise and finalize the procedure with the lab coordinator.
- Find all chemicals, apparatus, and tools for the preparation.
- Finish preparation under the supervision of lab coordinator.
- Clean up.

This task requires lab assistants to apply the chemistry concepts they learn in the lecture to their job assignment. It incorporates planning, reasoning, generating a workable solution, and building problem-solving skills in the process. Usually, it takes a long time on their first attempt because most of the lab assistants are being exposed to this type of open-ended task for the first time. It is recommended to group an experienced student with a new student in their first preparation assignment.

Job 2 is to prepare 500.0 mL of 0.130 M $KMnO_4$ aqueous solution. Lab assistants are reminded that some chemistry concepts such as molarity, solubility, and molar mass should be considered while writing the detailed procedure of preparation including calculations.

Lab assistant's initial response:

- Calculation:
  Mass of $KMnO_4$ = moles of $KMnO_4$ × molar mass of $KMnO_4$
  = (0.130 M × 0.500 L) × 158.03 g/mol
  = 10.3 g
  Note: sometimes students will present wrong data because they are a little confused with the chemistry concepts involved, such as molar mass and molarity in this case. They are guided to review the related contents in their text book and notes and come back with the correct answer. The first and second practices usually take a long time to finish. After a few practices, it only takes a few extra minutes for students to get the calculation results. This is a perfect example of applying chemistry concepts in a real preparation.
- Preparation procedure:
  Weigh 10.3 g of $KMnO_4$, measure 500 mL of H_2O, dissolve the solid with H_2O.

As shown here, this procedure lacks details. During the discussion, the lab coordinator encourages the lab assistants to add more detail by asking them questions such as how to weigh the solid, how to measure the liquid volume, how to dissolve the solid, and which apparatus should be used. The lab assistants then seek answers by locating all the glassware and supplies they need and adding details to the procedure. After revision, a detailed procedure is written, as shown here:

1. Locate all items: balance, weighing paper, spatula, $KMnO_4$, deionized water, 500 mL volumetric flask, powder funnel.

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J. Chem. Educ. XXXX, XXX, XXX−XXX

2. Weigh 10.3 g of $KMnO_4$ on a weighing paper using a spatula to transfer the solid from the commercial bottle.
3. In the fume hood, transfer weighed $KMnO_4$ to the 500 mL volumetric flask by using the powder funnel.
4. Add deionized water to the volumetric flask until half full by using the same funnel and swirl the contents to hasten this solution. Add more solvent and again mix well. Once the solid is dissolved, bring the liquid level almost to the mark, and allow about 1 min for drainage. Then use a dropper to add the deionized water until the level reaches the mark.[11]
5. Firmly stopper the volumetric flask and invert it repeatedly to ensure thorough mixing.[11]
6. Transfer the prepared solution to a dry, labeled 500 mL amber bottle.
7. Clean the volumetric flask, powder funnel, and spatula and put the $KMnO_4$ chemical bottle to the original shelf place.

Compared to the initial student response to the task, the revised version is much more organized, detailed, and professional. Usually it takes two to three revisions to finalize the procedure's details, especially for new lab assistants. Once the procedure is approved with the help and supervision of the lab coordinator, our lab assistants successfully finish the preparation as expected. After more practice, students usually have a deeper understanding about the chemistry concepts and the lab preparation. They are more comfortable handling the preparations and are more confident and independent. From calculations to writing procedures, students are very excited that they can use the knowledge that they learned in the lecture for tasks in the lab. Some lab assistants said that they feel a sense of accomplishment when they know students will perform experiments by using the solution they made for the class. Self-confidence is very present in this case. Thus, after carefully planning the details, the two lab assistants accomplished the job 2 task professionally and efficiently.

As shown in Case 1, this type of open-ended task provides the lab assistants an opportunity to think critically about their job assignment. Throughout the year, students are motivated by active involvement in the job planning and decision making process. They also learn how to play a role as a team member while working with other lab assistants. During the work, they learn to apply what they learned from their chemistry class to the job assignment. They practice analyzing tasks, seeking direction, and meeting expectations. These decision-making practices help them to build their confidence and has a life-long benefit, reflected by the positive feedback from the survey.

Case 2: Organizing in the Laboratory

Besides preparation, another main area that is part of a lab assistant's routine work is organizing chemicals and supplies in the classroom and the stock area.

When managing a stock area, such as the stock room, chemical cabinet, or flammables cabinet, safety and user friendliness are always the two key components that are taken in consideration. When lab assistants are assigned the job to put supplies in order, a few questions are intentionally set up for them: "Do you think this arrangement is good for daily use?" and "Is there any better solution to make it more user-friendly or save more space?" Students are reminded to ask these questions all the time at work. It turned out that a lot of the time, students came up with great new ideas, sometimes simple but practical, to make improvements for the department. Here are some examples:

- All the weighing paper and weighing boats were stored in the stock room. They were put into the classroom whenever there was a need before the lab section started. One lab assistant suggested moving these supplies to the cabinet next to the balances in each lab based on the lab size and usage. Now these supplies are easy to access.
- Stock room shelf space is always in demand because accommodating supplies in limited space is a great challenge. While stocking a new shipment of glass beakers, one lab assistant student came up with an idea of stacking the sets of beaker with different sizes in a set, instead of spreading each beaker on the shelf. This simple change of organizing strategy has saved a lot of shelf space so that more glassware is stored by using the same amount of space.
- Each lab has a chemical storage area and supply storage area. Preprepared chemicals used to be arranged in the storage by alphabetical order. After working in labs and dispensing class bottles a few times, one lab assistant suggested organizing the class bottles by experiment instead of putting everything in one big area. It would not only save the preparation time before class but also avoid mistakes such as misreading labels among many chemicals. His idea was further refined by other lab assistants and the lab coordinator. A few weeks later, with a small investment in organizing bins, all class bottles were organized in each labeled bin. Any chemical that needed special storage was also clearly labeled on the bin with its desired location. The new arrangement has been used in each teaching lab since then. This is a great example to our lab assistants that their smart ideas can make a big difference.

When our lab assistants noticed their ideas were adopted by the department, they were highly motivated and continued to be problem solvers, not just workers on the job. Some of them said they started to be more aware of their surroundings and tried to make improvements in their dorms, at home, and in the classroom. Throughout the years, while lab assistants were making their contributions to the department, they are also the beneficiaries from this job experience.

WAGNER COLLEGE UNDERGRADUATE LAB ASSISTANT PROGRAM

Wagner College is a liberal arts college with annual enrollment of about 500 undergraduates. About 25% of the students enroll in a science-related program including premed, predental, and physician assistant programs. Each semester, lab assistant job openings are available to students who are interested in being a science major or in a healthcare related program. Students get the job opening information from the school Web site and apply through the financial aid office. Because it is a first-come, first-served-based process, no selection of students was involved in the hiring process. From 2007 to 2014, the chemistry division of the Physical Science Department hired total 31 student lab assistants to work in our teaching laboratories. A total of 22 of them were work-study students through financial aid, and 9 of them were paid by regular payroll. Twenty-four of them retained the job and worked for two or more semesters. This high job retention clearly shows our new learning and work experience is highly attractive to students. Among them, there were 3 students (all chemistry majors) who worked for all

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J. Chem. Educ. XXXX, XXX, XXX−XXX

4 years while at Wagner College. Two of them are now studying at medical or dental school. One student graduated in May 2013 and found an industry position immediately after graduation and plans to pursue a chemical engineering master's degree. As shown in Figure 1, among all lab assistants, twenty-six of them are science and health related majors, and twenty of our students are majors or minors in chemistry. Eleven of our graduated lab assistants were accepted into medical, dental, pharmacy, or veterinary schools or physician assistant programs. Three of them continued on to graduate school in chemistry or biology. Although we are unable to track the undergraduate students record of continuing science-related study after graduation, the high rate of continuing science-related study among lab assistants (14 out of 31) indicates their high learning performances in the class.

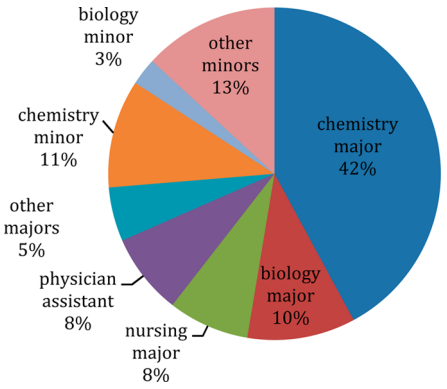

Figure 1. Distribution of Wagner College undergraduate lab assistants' majors and minors, 2007−2014.

LAB ASSISTANTS AND FACULTY FEEDBACK

To measure lab assistants' perception of how this job experience affected their academic and career skills, an anonymous online survey was conducted. We were able to reach 21 former and current lab assistants. The results are shown in Table 1. Lab assistants positively responded (over 95%) that this job experience helped their understanding of chemistry concepts, awareness of lab safety and safe handling of chemicals, learning lab preparation techniques, and problem solving skills improve. A total of 76% of students felt that they had better time management in their other activities after the lab assistant experience. Additionally, 72% of students felt that they became more independent in their senior research study, and 86% of students felt that their learning confidence was improved after this job experience. The results also indicated that lab assistant job experiences helped students prepare for future careers, including working better with peers and supervisors. Sixteen alumni responded to the last statement, and 62% of them indicated that the lab assistant job helped them fit into their current job quickly.

Consistent with survey data, student comments also indicated that their lab assistant job experiences benefited their chemistry learning and future study. A few students' comments are quoted below:

> *Working as a lab assistant was a great experience for me. It not only encouraged me to continue on as a science major, but it also helped me prepare for my future in the medical field. Working with chemicals, I have learned what is appropriate to mix and what cannot. This comes in handy for when I prescribe medication to patients knowing which prescriptions cannot be mixed. It also helped me with an understanding in my Organic Class. Since working in the lab, it was easier for me to understand what is going on and how to approach the subject in a matter that allowed me to succeed in the class.*
>
> *Working as a lab assistant honed my sense of responsibility. My lab assistant job experience at Wagner College helped me to better time manage in my other activities especially in my Dental clinic rotation at XXX University, for instance, instead of treating one patient at a time I manage to treat two patients now. It helped me learn preparation techniques in my other science courses as well as in Dental school especially when I see my patients during my clinical times. It helped me also better understand the chemistry part in Dental clinic when I use different Dental materials like composite and amalgam materials.*
>
> *I believe that I learned a lot through my experience as a lab assistant. I gained a plethora of knowledge in the general functioning of both teaching and research laboratories at a small liberal arts college. ...the current trend in Medical Education is geared toward independent study and learning though doing. I believe that my time working in the laboratories at Wagner allowed me to quickly adapt readily to this style of learning while many of my peers struggled.*

Table 1. Lab Assistants Survey Responses about Lab Assistant Job Experiences

Survey Statement: After my lab assistant job experience,	Strongly Agree, %	Agree, %	Neither Agree Nor Disagree, %	Disagree, %
I felt that I had a better understanding of chemistry course materials.	62	38		
I was aware of lab safety and safe handling of chemicals in my science courses.	95	5		
I learned many preparation techniques that helped me in my science courses.	71	29		
I had better time management in my other activities.	38	38	24	
I worked more independently in my senior research project.	29	43	28	
I felt that I was more confident in my science courses.	38	48	14	
I became more creative in my academic work.	24	43	29	5
I improved my problem solving skills.	43	52	5	
My lab assistant job experience helped me decide to be a science major/minor.	29	5	33	33
I felt that I worked better with peers at other job experiences.	43	38	19	
I felt that I worked better with supervisors at other job experiences.	56	29	14	
I felt it helped me fit into my current job quickly (for alumni only).	31	31	31	6

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J. Chem. Educ. XXXX, XXX, XXX−XXX

As a lab assistant I learned many valuable skills and techniques that helped me get a position as a graduate assistant in the Microbiology department and later on my job as a science teacher. Having a laboratory skill set was something that was very valuable and has helped greatly in my career.

I enjoyed working in the chemistry lab. After preparing chemicals and helping with lab set up I found my own lab time to be much easier.

It was great! It really prepared me toward my future jobs...how to work better with others and be a team player. I learned a great deal from my job as a lab assistant for the Chemistry department at Wagner College. Since I worked in the lab for four years, I gained valuable knowledge about various lab techniques and instruments, which assisted me when I was completing my Senior Honors Thesis Project. The safety aspects of the lab experiences also helped me in my current job.

The author acknowledges that only a small group of students have the lab assistants' job opportunity in their college years. However, the majority of the lab assistants agreed that this job experience motivated their learning confidence and improved their problem solving skills. Our faculty members also made positive comments on the lab assistants who joined their research group for senior thesis research. They found that the lab assistants stood out in the research project among the student group and showed solid laboratory skills and problem-solving skills during their research. Lab assistants also showed strong leadership and independence among the team members.

■ SUMMARY

Promoting thinking and chemistry learning through lab assistant job experience in college is practical and meaningful. The promotion of student-centered, inquiry based chemistry lab assistant program allowed students to use the knowledge they have learned in the lecture and apply thinking strategies to solve practical problems. It prepared them intellectually and practically for their future science career and provides a new learning model for chemistry education in a practical way.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: hongbin.yu@csi.cuny.edu.

Notes

The authors declare no competing financial interest.

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