CREATION OF A LABORATORY FOR
LA ACADEMIA NACIONAL DE BOMBEROS

SAN JOSÉ, COSTA RICA

An Interactive Qualifying Project
Submitted to the Faculty of
Worcester Polytechnic Institute
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Abstract

The Academia Nacional de Bomberos (ANB) of Costa Rica is advancing its basic firefighter training to provide college level courses and ultimately graduate degrees in fire safety over the next five to ten years. In order to provide these courses, the Academia must become certified as a parauniversitaria. In Costa Rica, a parauniversitaria is an institution of higher education. There are several regulations the Academia must follow to complete their certification. Their first priority is to improve their training process by creating a chemistry laboratory for testing, demonstration, and research. Our project team assisted the Bomberos toward attaining this goal by creating a design for the conversion of an existing classroom at the ANB into a chemistry laboratory. Our team determined regulations, potential suppliers, safety procedures, and equipment for the laboratory, and proposed a potential design for the renovation. Ultimately, we designed a scientific laboratory that best fit the Bomberos' needs and requirements while remaining under budget.

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We would like to thank Professor Melissa Belz, from the Interdisciplinary and Global Studies Division, and Jim and Marcela Music for their constant dedication to developing lasting relationships with sponsors and creating project opportunities in Costa Rica for the students of WPI. Their efforts over the years at the Costa Rica Project Center have continuously helped shape various areas of the country, and have provided students with opportunities to participate in impactful projects within a different culture.

We would like to thank our advisors James Chiarelli and Darko Volkov for their support, knowledge, and guidance throughout the ID 2050 course and IQP program. Their dedication to our projects and willingness to help whenever needed enabled us to complete our project in a sophisticated and professional manner. Their ability to make every sponsor meeting with the Bomberos was generous and helpful, and for that we are enormously grateful.

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Lastly, we would like to extend thanks to Worcester Polytechnic Institute for giving us the opportunity to complete our project with the Bomberos in Costa Rica.

Executive Summary

Introduction

Firefighters train to handle any situation that arises in order to save the lives of those affected by fires and natural disasters. Countries around the globe are implementing programs to improve their firefighting training and offer courses in firefighting and life safety. Costa Rica is one of the countries currently developing formal firefighting programs and degrees in fire safety.

El Cuerpo de Bomberos is the official firefighting organization in Costa Rica. They are funded by the National Bank of Costa Rica and have over seventy-six stations operating throughout the country. The Academia Nacional de Bomberos (ANB) is the central training facility of the Bomberos. The Academia now plans to expand beyond basic firefighter training to offer college and graduate level degrees in fire safety. In order to offer these courses, the Academia must become certified as a parauniversitaria.

Parauniversitaria offers a level of education between high school education and full universities, and generally focuses on technical areas (SINAES, 2019). Part of the ANB's certification process is to develop a chemistry laboratory that will be used for testing, demonstration, and research. The lab will host coursework and allow the Academia to conduct research and training activities in areas including chemistry, chemical fires, extinguishing, and fire density testing.

Goals, Objectives, and Methods

The goal of our project was to work with the ANB to create a chemistry laboratory that best suits the Bomberos' needs and requirements while remaining under budget. The necessary components of creating an effective laboratory design include meeting legal regulations, fire safety requirements, and building safety codes. In order to complete the project, we outlined the following project objectives:

1. Clearly define the building safety requirements for a laboratory.
2. Examine models of how other Costa Rican universities have met these requirements.

3. Determine experiments relevant to the ANB and necessary equipment.
4. Determine how to obtain the laboratory equipment under the Academia's budget.
5. Determine the best set of designs for remodeling the classroom into a laboratory.

First, our team gathered information regarding general life safety codes and building codes such as the International Building Code (IBC) and the Uniform Building Code (UBC). We also examined the National Fire Protection Association (NFPA) Standards that correspond to our project, including:

- NFPA 1 (Fire Code);
- NFPA 101 (Life Safety Code);
- NFPA 13 (Installation of Sprinkler Systems);
- NFPA 25 (Testing & Inspection Checklist for Sprinklers & Fire Protection Systems);
- NFPA 45 (Fire Protection of Laboratories Using Chemicals).

The laboratory designs comply with these codes in order to ensure that the lab meets safety standards and is a safe environment for occupants in the event of an emergency.

Next, our team investigated the chemical and fire protection laboratories at WPI as well as at the Universidad de Costa Rica (UCR) and the Instituto Tecnológico de Costa Rica (TEC). Both TEC and UCR offer degrees in science-related fields. They served as models for laboratory designs and practices because they are subject to the same legal and education requirements as the Academia. At each laboratory we explored these research questions:

1. What are common laboratory designs and what are their advantages and disadvantages?
2. What equipment do other laboratories use? Which items are the most essential? How do they procure the equipment and stock chemicals?
3. What safety practices do they use?

We used these case studies to craft our designs for the laboratory, to propose a list of experiments for the Bomberos lab, and to find local suppliers. We contacted those suppliers about equipment and pricing, keeping in mind the Bomberos' initial budget, which was between 5,000,000 to 8,500,000 colones (10,000 to 15,000 USD) per year.

Findings

We spoke to Professor Kmiotek at WPI, Director Campos at UCR, and Professor Sandoval at TEC to develop a list of materials and equipment for the laboratory. We contacted local suppliers for pricing and provided a list of equipment that the Bomberos could include in the laboratory. The list of equipment (shown in the table below) includes basic chemical equipment such as beakers, test tubes, and pipettes, along with more sophisticated equipment like a calorimeter or fire experimentation lab kits.

Local equipment suppliers include Diprolab, a company in San José which sells basic laboratory equipment. Fisher Scientific is an international laboratory supplier and biotechnology company. Fisher Scientific provides some products that Diprolab cannot, such as fume hoods, calorimeters, and safety showers, but their products cost more due to international shipping fees. We recommend that the Bomberos use Diprolab for basic equipment and Fisher Scientific for items that they cannot procure locally.

Equipment	CRC per item	Possible Quantity	CRC Total	USD Total	Provider	Description
Benches	944000	4	3776000	6800	Fisher Scientific	Lab table. Alternately, build with local carpenter
Sink	294000	4	1176000	2116	Fisher Scientific	Drop-in epoxy sink. Alternately, from local suppliers/builders
Stools	14000	25	350000	625	Wal-mart	SImple wooden stool. Alternately, build with local carpenter
Balance	117000	2	234000	421.2	Diprolab	Local
Graduated cylinder 25mL	5700	8	45600	82.08	Diprolab	Local
Graduated Cylinder 50mL	6005	8	48040	86.472	Diprolab	Local
Graduated Cylinder 100mL	8270	8	66160	119.088	Diprolab	Local
Beaker 50mL	1190	8	9520	17.136	Diprolab	Local
Beaker 100mL	2060	8	16480	29.664	Diprolab	Local
Beaker 600mL	2900	4	11600	20.88	Diprolab	Local
Lab Coats	12000	25	300000	540	Diprolab	Local
Safety Glasses	1770	25	44250	79.65	Diprolab	Local
Hot Plate and Stirrers	348100	2	696200	1253.16	Diprolab	Local
Thermometer	3240	4	12960	23.328	Diprolab	Local
Eye wash and safety shower	300000	1	300000	540	Amazon, Haws, Hughes, EyewashDirect, etc.	
Bunsen Burner	15000	8	120000	216	Diprolab	Local
Total			*1904810*	*$3,428.66*		

In order to conduct experiments, the ANB needs to purchase a variety of chemicals. Based on our case studies, our team created the list of chemicals (right) most commonly used in basic chemistry courses. Our team researched chemical suppliers and created the following list of companies that sell chemicals locally and internationally:

Chemical
Acetone
Nitric Acid
Sulfuric Acid
DI Water
Ethanol
Phenolphthalein (Indicators)
Gasoline
HCl
Hexane
KHP
KI
KIO3
KMnO4
KOH
NaCl
NaOH
Toluene
Iodine
Total

- Laboratorios Químicos Arvi (Costa Rica);
- Tecnodiagnostica (Costa Rica);
- Sigma-Aldrich (international);
- Fisher Scientific (international).

The ANB can purchase basic chemical supplies from local companies and more specialized chemicals from international suppliers as needed.

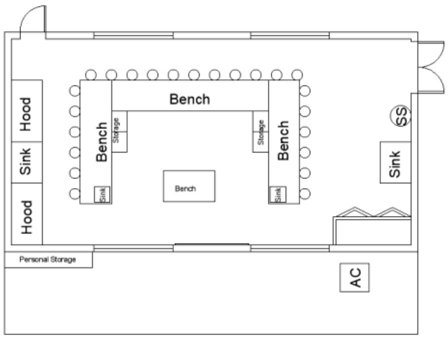
Our team also created a set of designs for the laboratory. Our preliminary designs included four lab benches, twenty-four stools, two fume hoods, a chemical storage locker, a safety shower and eyewash, a sink station, and a projector with a SMART Board. We recommend the Bomberos use a local carpenter for furniture such as laboratory benches and personal storage units. This will be less expensive than shipping the items to the laboratory.

Recommendations

After several design iterations, the Bomberos chose a layout that best fit their classroom, shown below. This layout can be completed over time depending on the Bomberos' budget. We also recommend that the Bomberos refer to the NFPA standards as they construct and run the laboratory, including but not limited to the list of standards we have provided. For our final design, we added an emergency door to provide additional means of egress and ensured the layout had enough space for students to stand up and work around the lab.

We also researched demonstrations used at other fire safety and chemical departments (WPI, University of Maryland, and Eastern Kentucky University) to determine experiments the

Bomberos’ could use in their new laboratory. The following list of experiments can be used for an introductory chemistry and fire safety course:



- Determining volume, mass and density of various objects;
- Determining the unknown concentrations of NaCl solutions;
- Determining flash points of various materials;
- Exploring different methods of ignition;
- Examining ASTM standards and the Carmody Combustible Hazards Trainer for other experiments.

Conclusion

To remodel an existing classroom into a chemistry and fire protection laboratory for the Academia Nacional de Bomberos, our team investigated the NFPA code books, several case studies of university laboratories, and conducted interviews and discussions to understand the details necessary to create the laboratory. Our team completed a 5-year floor plan that included an emergency egress floor plan and a remodeled fire protection and life safety plan. We gave the Bomberos a detailed list of equipment and chemicals and included locations, prices, and suppliers. We also provided a list of experiments that can be implemented into their courses. Our final estimate of the budget for the first year of renovating and equipping the laboratory was 11,600,000 CRC (around $21,000 USD), which is an overestimate of the actual price of using local suppliers and carpenters. Our project team hopes that our design will help the Bomberos create a laboratory and become a certified parauniversitaria. We hope that our project will help provide the Bomberos with years of successful chemistry and fire protection experiments.

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1 Introduction

Firefighters train constantly to prepare for the stresses and dangers of fire. They train for every scenario in order to be prepared to save the lives of those affected by fires and natural disasters. Many countries around the globe are implementing programs and courses to better train their firefighters. After the completion of these courses, students can be awarded degrees in firefighting and fire safety. Costa Rica is one of many nations seeking to develop formal firefighting programs and courses which lead to advanced degrees.

El Cuerpo de Bomberos is the official firefighting organization in Costa Rica. The Bomberos provide fire prevention and protection services in order to protect the people, environment, and infrastructure of Costa Rica. The organization began in 1865 following a series of fires in San José. Since their founding, the Bomberos have grown and become more organized and technologically developed. Currently, they are funded by the National Bank of Costa Rica and have over seventy-six stations operating throughout the country. The Bomberos are constantly working to improve the training of their firefighters as well as their technology and firefighting techniques.

The Bomberos first began training firefighters in 1965, led by Mario Zúñiga Orozco and Róger Fallas. Throughout the 1960's, trainers travelled to each station in an effort to train as many firefighters as possible. The firefighters learned the most up-to-date knowledge in fire safety, firefighting techniques, and emergency response. Over time, the training system improved. Instead of trainers traveling to each station, a central training facility was created and the training became more rigorous. In the 1990s, the Bomberos designated this central training facility as the national academy of firefighting, la Academia Nacional de Bomberos.

In the early 2000's, the foundations of the Academia were solidified, consisting of basic training as well as technical training including eight specialized courses and five complementary courses. As of 2015 the academy has improved its courses and facilities, which now include practice houses, a computer lab, search simulators, a rescue tower, and a large multipurpose field (Bomberos, 2020).

The Academia Nacional de Bomberos now plans to expand beyond basic firefighter training to offer college and graduate degrees in fire safety. Part of their progress toward this goal is to develop a testing, demonstration, and research laboratory. The lab will host coursework and allow the Academia to conduct research and training activities in areas including chemistry, chemical fires, extinguishing, and fire density testing.

The goal of our project was to work with the Academia Nacional de Bomberos to determine what needs to be included in a new chemistry laboratory. Necessary components of an effective laboratory design include meeting legal regulations, fire safety requirements, and building safety codes; researching equipment and potential layouts; and fitting the building design to the budget of the project and the number of people required to operate the facility. Our team was responsible for communicating with the users of the facility and other stakeholders to determine which laboratory equipment is most important and how it could be procured while staying under budget. Once the proper equipment was established, potential designs of the laboratory were created and narrowed down to a final design. This design can be used by the Academia Nacional de Bomberos in Costa Rica to remodel and equip an existing building as a chemistry laboratory so that the Academia can offer advanced chemistry and fire-related coursework.

2 Background

In this chapter we discuss the need for a laboratory in the context of Costa Rica and the Academia Nacional de Bomberos, the requirements we needed to research, and the laboratory case studies we investigated as models.

2.1 The Academia Nacional de Bomberos

The Academia Nacional de Bomberos (ANB) is located in San José, the capital city of Costa Rica. The ANB is a national academy that focuses on innovative training processes based on quality standards for the development of the knowledge and skills of the Fire Department and collaborators. Their mission is to train individuals in the fire department (firefighters, chiefs, and officials) using rigorous exercises and courses so that they are prepared for any scenario they encounter. The vision of the ANB is "to be a governing body in training for the emergency care and prevention that are the responsibility of the Fire Department, providing an excellent service in all activities" (La Academia Nacional de Bomberos, 2020). The ANB also offers other programs including Business Training Management, Administrative Management, and Teacher Management.

The Academia campus consists of an administrative building, three classrooms and a computer laboratory, a cafeteria, a tower and houses for firefighting exercises, and a large field used for multiple purposes. They offer a variety of courses for external students, firefighters, and firefighters-in-training. Course topics range from rescues from vehicles and collapsed buildings to teamwork and chain-of-command during emergencies. Beyond the programs it currently offers, the Academia now desires to offer more advanced courses and degrees in fire safety, including college degree level courses. The new laboratory will provide facilities for these courses and demonstrations in order to allow the Academia to offer advanced degrees.

2.2 Education in Costa Rica

Costa Rica has devoted much of its resources and investments to the health and education of its citizens. The disbanding of its military forces in 1949 has made public education a higher priority for the government. Part of that public education is the firefighting training offered by the Academia Nacional de Bomberos run by the Costa Rica Cuerpo de Bomberos (Embajada De Costa Rica En DC, n.d.).

In 1869, education in Costa Rica became free and mandatory for all its citizens. Since then, Costa Rica's education system has grown throughout the country. There are currently more than four thousand schools in Costa Rica. Costa Rica spends around 7.4% of its annual GDP (gross domestic product) on education, compared to 2.8% in Guatemala, 3.2% in Panama, and 5% in the United States (World Bank, 2019). The national literacy rate in Costa Rica has increased to 97.8% in residents at the age of 15 and older, and every community has public elementary and high schools. Compared to other Central American, Costa Rica is among the top few for literacy. Panama and Columbia both have the same literacy rate at 95%, while other Central American countries have lower literacy rates, such as Honduras, Belize, and Guatemala at 88%, 83%, and 79% literacy respectively (UNESCO, n.d.). The 97.8% literacy rate in Costa Rica is not as high as some more developed countries, such as the United States or Italy (99.9% and 99.2%), but it is still one of the highest in the world.

Costa Rica also has both public and private universities that offer excellent academics and financial investment. Tuition runs about 50% less than the average in-state rates of most U.S. public institutions. In proportion to average household income, however, U.S. and Costa Rican college educations cost almost the same (see calculations in Appendix A). Several private universities specialize in medicine, science and technology, architecture and design, and other fields. Universities are increasingly providing master's degree programs and MBA programs to the Costa Rican communities (Costa Rica's Education System, 2015).

In addition to those areas, the Academia Nacional de Bomberos now aims to offer advanced degrees in fire safety. These courses will better prepare firefighters in training and current firefighters deal with complex fire situations. In order to offer these degrees, the Academia needs to become certified as a parauniversitaria.

2.3 University Certification

In order to become certified as a parauniversitaria, the Academia must meet the requirements defined by el Consejo Superior de Educación (CSE; in English the Higher

Educational Council), a division of the Costa Rican Department of Education, the Ministerio de Educación Pública (MEP). CSE was created in 1951 as a body of the national government. It participates in the development of the national education system, focusing on quality and on adapting constantly to the needs of the country. Among its other functions, CSE approves projects to create new colleges, educational programs and plans of study, and evaluation programs (Consejo Superior de Educación, 2019). CSE regulates the educational system of Costa Rica at the following levels:

- Preschool education;
- General education (primary, secondary, and tertiary school totalling nine years of education);
- Diversified education in academics, technology, or arts (2 or 3 years of education);
- Higher level education, known as parauniversitaria.

Parauniversitaria offers a level of education between diversified education and full universities. Parauniversitarias generally focus on technical areas (SINAES, 2019). Their main goal is to offer training in two or three years for a given career. Most students are between 18 to 24 years of age, but there are also older students who did not immediately continue their studies after secondary school.

CSE's requirements for institutions seeking to become parauniversitarias include requiring them to define the degrees they will offer as well as the courses required in order to earn each degree. Currently, the Academia has a list of thirty-two classes that they plan to offer, with a focus in chemistry and fire chemistry. This list must be approved by CSE. Meanwhile, because the required courses will include laboratory work - such as chemistry and fire demonstrations - the Academia must have its own laboratory in order to offer the courses. This is the laboratory that our team was charged with designing using an existing classroom on the campus of the Academia. The existing classroom is described below.

2.4 Laboratory Specifications

The laboratory will be created by remodeling and equipping an existing classroom on the Academia campus. The classroom is a standalone building with a rectangular area of 84 square meters. Figure 1 below shows the current classroom as seen from the entrance. The room has one door and a separate small room by the entrance which in the past was used to conduct examinations. There are two large windows on each of the longer walls, and a whiteboard and SmartBoard on the wall opposite the door. The floor is tiled, and the room originally contained desks and chairs as in a normal classroom. The classroom has air conditioning and electricity connections, but no sprinklers. It currently does not have a water connection, but could be easily connected to a water pipeline which runs past it.

Figure 1: Current ANB Classroom

The budget currently allocated by the Academia to remodel and equip this classroom is around 5,000,000 to 8,500,000 Colónes (approximately 10,000 to 15,000 USD). This number is the budget estimate for each year. The Academia hopes to complete the laboratory over a currently unspecified time frame, which could range between 5 to 10 years. They will begin with a basic laboratory and develop it each year into a more advanced facility. This strategy allows them to purchase laboratory equipment over time as their yearly budget allows.

2.5 Case Studies

In order to develop viable designs for remodeling the classroom, our team conducted case studies of laboratories, including laboratory equipment and standards. Case studies were an important aspect of our research because the best way to design a chemistry laboratory is to look at existing laboratories and see how they are successful. We researched three chemistry laboratories, one in the United States and two in Costa Rica, as well as a fire protection engineering laboratory. We chose to study laboratories in both countries to see if there were any major differences in the equipment, suppliers, or safety procedures. The laboratories we studied were the chemistry laboratory at Worcester Polytechnic Institute (WPI), the Fire Protection Engineering (FPE) laboratory at WPI, the chemistry laboratory at the University of Costa Rica (UCR), and the chemistry laboratory at the Instituto Tecnológico de Costa Rica (TEC).

2.5.1 Worcester Polytechnic Institute Chemistry Laboratory

For our study of the WPI laboratory, we toured the chemistry laboratories on campus and met with Professor Stephen Kmiotek of the WPI chemical engineering department. The topics we discussed included laboratory equipment, laboratory suppliers, and laboratory safety procedures. A photograph of one of the WPI chemistry laboratories is shown in Figure 2 below.

Figure 2: Chemistry Laboratory at WPI

As we toured the WPI laboratories, we noted the important equipment in the labs. One of the most important features in a chemistry laboratory is the fume hood or hoods (a single fume hood is shown in Figure 3 below). Some laboratories, such as the labs at UCR and TEC, have only one fume hood in each room. In the picture above, fume hoods line every wall of the WPI lab. Having multiple hoods allows more students to conduct experiments at once, instead of rotating through using a single hood. The fume hoods ventilate toxic gases and smoke through a filter to the outside air. Each hood has a glass screen that could be pulled down to seal away the experiment from the rest of the room, allowing students to observe the experiment without causing any harm to themselves or disrupting the experiment.

Figure 3: Fume Hood at TEC

The next item that was present in all the laboratories was a standard sink at each station. These are used for students to wash their hands and any equipment that does not contain corrosive chemicals. Non-corrosive chemicals can also be disposed of in the sinks. Laboratory sinks will need to be added to the Academia’s existing classroom building.

Another item at each workstation in the WPI laboratory is a set of three labeled nozzles: one emits Air, another Gas, and the third Water. These connections allow students to utilize

Bunsen burners in their experiments, as well as to run water or air through equipment as needed.

Every laboratory had an eye wash station as well as a labeled Emergency Shower located in a central and easily accessible area of the lab. These are in place for emergency chemical contact scenarios, such as if toxic or corrosive chemicals came in contact with a student's eyes or body. Instead of trying to take care of it themselves and potentially causing more harm by rubbing the chemical deeper into their eyes or skin, students should use the shower or eye wash to completely flush chemicals from the skin or eyes.

Some other factors that were mentioned during our tour of the WPI lab were chemical benches, chemical lockers, balances, and common equipment such as beakers and other containers. The chemical benches are important to have in a lab because they are one of the primary work spaces. The top of the benches have a chemical resistant coating which is important for any chemical spills that happen during experiments. Also, the benches contain storage space underneath, where pieces of equipment such as Bunsen burners, beakers, and scales can be stored.

The chemical lockers are special storage containers that are fire resistant and can be used to store flammable chemicals. The chemical lockers were located in a separate storage closet in order to keep flammable chemicals away from ongoing experiments. According to fire code, when a lab uses chemical lockers they can reduce the number of sprinklers required in a storage room.

Balances are important in laboratories because many experiments involve weighing a material or chemical before and after it is tested. A good balance can be very expensive, but it is necessary to have in almost any laboratory. Lastly, beakers and other containers are necessary because they are very helpful when transporting chemicals around the lab and are commonly used to conduct experiments.

In order to supply the equipment described above, the WPI laboratory uses a handful of different suppliers. The main supplier used by WPI is Fisher Scientific. Fisher Scientific sells chemicals and laboratory equipment mainly within the United States. In their online catalog, they list over 220,000 items ranging from pipettes, balances, and centrifuges to organic compounds, acids, and bases. Products vary in price, from common chemicals to rare and expensive measuring devices. WPI also orders some equipment from Lab Safety Supplies, such as nitrile gloves.

With respect to safety in the laboratory, the WPI labs require students to wear safety glasses, laboratory coats, gloves, closed-toed shoes, and long pants whenever they are in the laboratory. Those with long hair must tie their hair back. All chemicals are carefully labeled to prevent mishaps. Chemicals are generally disposed of in labeled containers in order to be treated later; very simple chemicals such as low molarity bases can be washed down the drain. Experiments are generally conducted within the fume hoods. All people using the laboratory are educated on these safety procedures, how to use the safety eyewash and emergency shower, and the location of the nearest exits.

At the end of our tour of the WPI labs we asked Professor Kmiotek about the key characteristics of a good laboratory. Professor Kmiotek stated, “There isn’t much that can’t be achieved as long as you keep your lab neat and organized” (Kmiotek, 2019). With a laboratory that is clean and well-organized and which contains the essential equipment described above, researchers can conduct almost any experiment they desire. There are no limits with these two simple guidelines, and this is what we aimed to achieve with the laboratory designs for the Academia.

2.5.2 Worcester Polytechnic Institute Fire Protection Laboratory

In addition to its chemistry laboratories, WPI recently constructed a state-of-the-art Fire Protection Engineering (FPE) laboratory. Fire protection engineers apply science and engineering principles to protect humans, property, and the environment from fire. WPI was the first graduate program in the United States to offer fire protection engineering, and now offers courses in fire safety including courses on fire modeling, fire protection systems, building analysis, and industrial fire protection.

The fire protection engineering laboratories at WPI include a combustion laboratory, FPE performance laboratory, and FPE fundamentals laboratory. The combustion lab is used to study fundamental problems in combustion, explosions, and fire safety. The facility houses multiple fume hoods to ventilate and study the smoke and other emissions from the experiments. The lab also has pressurized gasses such as oxygen, nitrogen, carbon dioxide, and carbon monoxide for use in different experiments conducted in the lab. Equipment in the combustion lab includes a laser for measuring velocity, an environmental chamber, an oxygen analyzer for corrosive environments, and a gas analyzer for measuring carbon monoxide, carbon dioxide, and oxygen vapor.

The FPE fundamentals lab equipment includes a cone calorimeter, a fire propagation apparatus, ovens, hooded bench spaces, and other measurement tools which allow researchers to conduct small-scale experiments and tests. These measurement tools include thermogravimetric analysis (TGA) and a differential scanning calorimeter (DSC). TGA measures the mass of a sample over time as temperature changes, which provides information about phase transitions and reactions. DSC measures the amount of heat required to increase the temperature of a sample. These devices are used to study materials and how they burn, not just for fire but for thermal decomposition of materials in general.

The FPE performance lab is 190 square meters (2,045 square feet) with a ceiling 9.2 meters tall (30 feet), which allows for construction of tests specimens up to two stories tall. Equipment in this laboratory includes a calorimeter with a 6-meter square (65 square feet) exhaust hood for testing open burning fires, exterior fires, and external fire conditions. The equipment in each of these laboratories provides an idea of the fire-specific equipment that could be procured in the future for the Bomberos laboratory, depending on the topics the Bomberos plan to study.

2.5.3 University of Costa Rica Chemistry Laboratory

Our team next visited the chemistry laboratory at the University of Costa Rica (UCR) in San José. The University of Costa Rica is a public university funded by the government of Costa Rica. It was founded in 1940 and hosts over 40,000 students and 1,400 current research projects. UCR offers degrees in areas from biology and chemistry to economics and art, and has a variety of laboratories. The laboratories most relevant to the ANB are UCR's chemistry laboratories, shown in Figure 4 below, which are used for research in the basic sciences.

Research taking place in the basic science laboratories includes topics such as the degradation of pollutants, water quality, and electrochemistry and chemical energy (Universidad de Costa Rica, 2019).

We toured the basic chemistry laboratories, and noted many of the same features present in the WPI labs, including fume hoods, sinks, gas and water connections, and acid-resistant benches. There were also a few differences between the two labs. UCR stores its chemicals and chemical waste in racks. Less dangerous chemicals are stored in the lab, while more dangerous chemicals are stored in a separate room. In older laboratories, UCR has fans in the windows to ventilate gases, whereas the newer labs at WPI have air circulation systems to completely change the air in the room multiple times per hour.

Along with viewing the laboratory at UCR, our team spoke with Cristain Campos, the director of the chemistry department. Director Campos provided us the names of local and international suppliers as well as a rough price estimate for the large equipment used in the chemistry labs. Local suppliers included the laboratory equipment company Diprolab, while international suppliers included the chemical supply company Merck. Basic equipment such as glassware, balances, and safety glasses could be obtained from Diprolab, while the most expensive laboratory items such as fume hoods would need to be ordered in advance and imported by international companies. Director Campos also mentioned that permits must be obtained in order to purchase certain chemicals, as described in section 2.8.

In addition, we inquired about UCR's storage for chemicals and standards that the chemistry labs follow. UCR stores low-risk chemicals in the lab in cabinets and fume hoods, and are also constructing a separate storage facility for higher risk substances. Their buildings follow standard building and life safety codes. Additionally, UCR is constructing a treatment plant to treat the waste chemicals from their own laboratories.

Figure 4: Chemistry Laboratory at UCR

2.5.4 Instituto Tecnológico de Costa Rica

To gain a better understanding of chemistry laboratories in Costa Rica our team also visited the laboratories at the Instituto Tecnológico de Costa Rica (TEC). TEC is a public institution located in Cartago, Costa Rica, providing education in the fields of science and technology. While visiting the laboratories at the TEC our team focused on the equipment present in each lab, the most common chemicals, storage of substances, and the safety practices in use. Professor José Sandoval gave us a tour of the TEC organic and analytical laboratories, shown in Figure 5, and answered questions about them (see list of questions in Appendix B).

In the two laboratories our team found that each of the six workstations had gas connections, an electrical outlet, and under-the-bench storage. Each workstation had enough space for three students to comfortably work and conduct experiments. The bench tops were made out of marble, which Professor Sandoval did not recommend because it stains easily. In each laboratory there were five sinks, one at the end of each of the three benches and two common sinks at the back of the laboratory. At the back of each lab there was one fume hood, which would be shared by the twenty-four students when class was in session. Also at the back of the lab there was a safety shower and eyewash station directly next to an emergency exit.

The laboratories had storage cabinets at the front of the lab where benchtop equipment such as hot plates, balances, and Bunsen burners were stored when not in use. On the side of the laboratory there was a set of lockers where students could store their belongings while working in the laboratory. The chemicals were stored in racks in a separate room to the side of the lab with sprinklers above. The store room also contained racks for glassware. The gas cylinders that supply the laboratory pipelines are stored in a small separate building outside of the laboratories to minimize damage from a fire or explosion.

Figure 5: Chemistry Laboratory at TEC

We asked Professor Sandoval to provide us with a list of chemicals used in TEC's basic chemistry courses. He told us that the chemicals TEC uses most commonly include:

- Acetone;
- Hexane;
- Alcohols such as ethanol;
- Indicators for acids and bases;
- Acids such as sulfuric acid, hydrochloric acid, and nitric acid;
- Bases such as nitrogen hydroxide, potassium hydroxide, and calcium hydroxide.

These chemicals and the chemicals used at WPI gave us an idea of what materials the Bomberos would need for their basic chemistry courses.

2.5.5 Future Directions of Inquiry

The ANB plans to begin with basic chemical and fire coursework, but may in the future expand to fire and fire protection research. For this reason, our team researched a variety of other institutions which conduct fire research. In the future, the ANB could contact the following organizations or use them for information about current fire research investigations, materials, or equipment.

The Underwriters Laboratories Firefighter Safety Research Institute (UL FSRI) in the United States works with fire departments and research groups to “advance fire research knowledge and develop cutting edge, practical fire service education aimed at helping firefighters stay safe while more effectively protecting people and property” (UL FSRI, 2020). UL FSRI conducts research in areas including ventilation, suppression, building construction, and fire dynamics. Depending on the research the ANB plans to conduct in the future, UL FSRI could provide examples of experiment designs and expanded laboratory layouts.

The National Institute of Standards and Technology (NIST) Engineering Laboratory’s Fire Research Division conducts both laboratory and large-scale experiments to “quantify the behavior of fire and means to reduce the impact of fire on people, property, and the environment” (NIST, 2020). The NIST Fire Research Division researches topics ranging from firefighter protective equipment to wildfires. Similar to UL FSRI, this laboratory’s research may provide the Bomberos with examples of future research topics and equipment.

Safety Engineering Labs, Inc. (SEL) is a company that offers fire testing and research services (SEL, 2020). Their laboratory equipment includes a scanning electron microscope, metallurgical microscope, Fourier Infrared Spectrophotometer, thermal imaging radiometer, and digital x-ray system. These labs can be used to test for flammability and combustibility, analyze materials and compounds, and measure the impact of fire retardant chemicals and devices. The ANB may want to examine which if any of the above equipment would be relevant for their future research.

The ANB may also want to research or contact schools which offer courses and degrees in similar areas. Such schools include WPI's FPE program, the University of Maryland's Department of Fire Protection Engineering, and the National Fire Academy. A further list of fire research schools can be found through the National Fire Protection Association (NFPA, 2019) and the Global Fire Research website (Global Fire Research, 2020).

2.6 Experiments

Along with case studies of laboratories, our team gathered information about common chemical and fire safety laboratory experiments. As they plan which courses to teach, the Bomberos need an idea of what kinds of experiments those courses involve, and therefore what materials they need. The Bomberos provided our team with a draft syllabus for their chemistry course (Appendix C). The syllabus covers atomic structure, chemical compounds and stoichiometry, thermochemistry and heat of combustion, organic compounds, and the theory of fire. We examined comparable chemistry and fire-related courses at WPI; the University of Maryland FPE department, which offers both undergraduate and graduate FPE degrees; and Eastern Kentucky University, which offers three bachelor's degrees in fire-related fields. Knowing what experiments other institutions conduct can help the Bomberos determine which experiments to run in their own lab.

At WPI, the basic chemistry courses are Chemistry 1010 and 1020. The laboratory experiments for these courses focus on molecularity and reactivity. Basic skills challenges include determining volume, mass, and density of various objects; determining unknown concentration of NaCl, acid, and metal solutions; and determining the stoichiometry of Cu-glycine and Zn-iodine. Students also complete larger projects which include synthesizing cadmium selenide nanoparticles, extracting and separating pigments from a green leaf, constructing a phase diagram for a solvent mixture, and determining the ideal gas constant and the composition of an alloy.

At the University of Maryland (UMD) Department of Fire Protection Engineering, one of the fire laboratory courses is ENFP 420: Fire Assessment Methods and Laboratory (see syllabus in Appendix D). This course covers topics such as ignition, flame spread, and rate of heat and smoke production from flammable gases, liquids, and solids. Laboratory activities begin with laboratory safety and laboratory skills. The rest of the course consists of five larger projects. One is a standard test method for flash and fire points using a Cleveland open-cup tester. The flash point of a material is the lowest temperature at which the liquid gives off vapor that forms an ignitable mixture in the air above it, while the fire point is the point at which this mixture burns continuously for at least 5 seconds. Flash points are used in regulations such as shipping laws to define flammable and combustible materials (ASTM, 2020). Knowing the flash points of materials and how they ignite helps firefighters understand the dangers of fire situations and the flammability hazards of various materials. Other experiments used in the UMD courses include testing the smoke generated by solid materials using a smoke chamber; testing heat and smoke release using an cone calorimeter; determining ignition and flame spread properties using a cup burner; and determining minimum gaseous flame extinguishment concentration using a cup burner.

Notably, the procedures for each of these projects can be found online as standards published by the American Society for Testing and Materials (ASTM) and by the NFPA. For example, the flash and fire point experiment can be found by searching for ASTM D92 (see Appendix D for the standard codes for other experiments). These standards are currently available for purchase at around 28,000 CRC each ($50 USD). The Bomberos may decide to purchase them or may have other contacts who already have access to them. Either way, these standards are helpful for the Bomberos' understanding of the process and materials for these particular experiments, as well as a point of exploration for other experiments to demonstrate in their lab.

Eastern Kentucky University's (EKU) undergraduate Fire Behavior and Combustion course also involves laboratory experiments, some of which are based on ASTM standards. Like UMD, one experiment EKU conducts is an open-cup flash point test; another is a closed-cup flash point test. A third experiment is a flammability range test, which demonstrates that the air-vapor ratio for a given fuel must be within its flammability range before undergoing combustion. This experiment can be conducted with a small spark plug chamber, such as one the Bomberos already possess which was constructed by a local supplier. Another experiment is a candle demonstration of basic fire concepts such as protection and suppression. A fifth demonstration demonstrates various ignition methods (spark, open flame, light bulb) and surface-to-mass relationships for flammable liquids (e.g. gasoline) and solids (e.g. wood). A sixth experiment demonstrates heavier than air vapors and flame spread using an alcohol lamp.

EKU also uses demonstrations from the Carmody Combustible Hazards Trainer (Trinity Corporation, 1984), which is a resource manual detailing over 20 fire-related demonstrations. The link to access this manual can be found in References. EKU also provides examples of laboratory documentation and procedures in the form of write-ups of the laboratory experiments. These reports include emergency procedures and material safety data sheets (MSDS) for potentially hazardous materials. One example of an experiment description from EKU can be found in Appendix E.

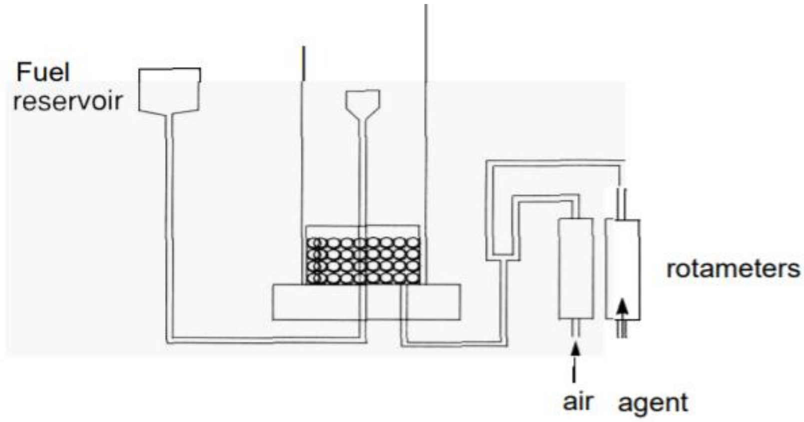
2.7 Equipment for Fire Experiments

The ANB laboratory is meant to be used as a demonstration and experimentation space to study chemical fires, chemistry, fire density, and extinguishing systems. In order to improve firefighting procedures, firefighters must study the science of fires: the conditions in which they start; how they spread; and how they can be extinguished. Studying each of these subjects requires certain equipment and safety procedures. The basic equipment used in a chemistry laboratory was detailed in the case studies above. Beyond that, the Academia may select other equipment in order to conduct fire-specific experiments, such as those described in 2.6. We examined the key equipment from these studies for the Academia's reference should they choose to expand the capabilities of the laboratory in the future.

Based on our visit to the WPI FPE laboratory, the essential instrument used to study fires, how materials burn, and fire emissions is a calorimeter. The main purpose of a calorimeter is to measure the heat involved in a chemical reaction. This is because the heat released by a burning sample is directly related to the amount of oxygen consumed during the combustion (NIST, 2018). This means that the heat also correlates with the severity of the fire and its growth rate. Additionally, calorimeters measure the amount of material burned, the time it took to burn, at what temperature it began to burn, and which gases were released from the burning of a given material. Researchers can use this information to understand what materials and chemicals are helpful to contain fires, which are the most fire-resistant, and which release the most toxic gases for human and animal consumption. This information can then be used to determine which materials are best to use in buildings. Different calorimeters can measure fires of various sizes, ranging from samples a few centimeters in diameter at bench-top calorimeters to burns as large as a forty square foot area, three stories high for large-scale calorimeters. The Academia would likely acquire a smaller calorimeter to fit in the classroom, unless they expand the laboratory to house a larger apparatus.

The other equipment in the experiments described in 2.6 ranges from the everyday to specific measuring devices. Everyday items include candles, frying pans, and balloons. More specific devices include a spark plug chamber, smoke chamber, and cup burner. The Bomberos already have a small spark plug chamber provided by a local supplier. This allows them to conduct small-scale fire and explosion experiments. A smoke density chamber is an instrument that measures the specific optical density of smoke generated by materials they burn (FTT, 2020). This device may be most useful to the Bomberos farther down the road after the laboratory has been equipped with more basic and widely-applicable instruments. A cup burner, shown in Figure 6 below (Robin, M.L.. and Rowland, T.F., 1999), is a device which falls under ISO 14520-1, a standard published by the International Organization for Standardization (ISO). It was developed by Hirst and Booth in the 1970s and is widely used to test flash points, fire suppression, and extinguishing agents. Further materials for the laboratory can be found in the Carmody Combustible Hazards Trainer and other experiment descriptions, depending on which experiments the Bomberos decide to conduct.

Figure 6: Hirst and Booth Cup-Burner Apparatus



Firefighters can also study different strategies for extinguishing fires. The strategies used to extinguish flames vary depending on those characteristics. For example, fires that burn flammable liquids or gases cannot be extinguished with water because the water can spread the fuel and fire instead of extinguishing it. Current types of fire extinguishers include water, water mist, water spray, foam, dry powder, carbon dioxide and wet chemical. Studying fire extinguishing and sprinkler systems is important in order to understand what materials work best to extinguish certain types of fires and how they are best applied. Laboratory equipment to study fire extinguishing and sprinklers generally involves a wet laboratory space, with sprinkler racks to examine the characteristics of different sprinkler layouts. The Academia would likely need to expand the existing laboratory in order to study these types of systems.

2.8 Chemical Permits

The ANB will need to purchase various chemicals in order to conduct experiments in the laboratory. In 2017, Costa Rica implemented the Globally Harmonized System (GHS) of classification and labelling of chemicals. GHS is a system designed by the United Nations to standardize the labeling of chemicals (OSHA, 2005). It includes defining their health, physical, and environmental hazards, classifying chemicals for comparison, and communicating hazard information on labels and Safety Data Sheets. On June 29, 2017 the government of Costa Rica published the executive decree No. 40457-S, which requires workplace and supplier chemicals to be labelled in accordance with GHS. Additionally, on November 2, 2017 executive decree No.

40705-S stated that in order to be registered, hazardous chemicals must have a GHS-compliant safety data sheet (ChemicalWatch, 2018).

In practice, this means that only chemists with permits can register and acquire chemicals. Companies that sell chemicals acquire these permits and fill them out on behalf of their customers. This means that the Bomberos do not need to acquire permits themselves, unless they desire to do so in the future for ease of access or for some specialty chemicals. At the start, the Bomberos can purchase chemicals from licensed chemical providers who will complete the permitting for the products.

2.9 Fire Protection and Life Safety

Finally, the new laboratory will be subject to fire protection and life safety codes. In every building, new or pre-existing, there are building codes, fire codes, and life safety codes that must be followed to ensure safety within buildings and to pass inspections by the board of inspectors. There are more than 300 different code books published by the National Fire Protection Agency (NFPA), International Building Code (IBC) and Uniform Building Code (UBC). These code books are highly detailed and apply depending on the type of building, the building location (country, town, or city, etc.), what the building is near, and what the building will be used for, among other specifications. The codes provided by the NFPA, IBC and UBC provide rules for designing and constructing buildings so that in case of an emergency or natural disaster, the building remains as safe as possible. These codes are crucial for the safety of every building and its occupants.

The codes most relevant to the Academia's future chemistry laboratory are NFPA 1, NFPA 45, NFPA 101 and NFPA 54. These codes cover the fire and life safety requirements set out by Costa Rica nationally, as well as the city of San José locally. Some countries and cities adopt codes other than NFPA. However, if NFPA is also adopted, it will overrule the other codes and be the code that is followed for regulations. NFPA overtakes other codes where adopted because it is widely considered to be the most detailed code. NFPA covers every general code set forth by other codes such as IBC and UBC, as well as the much more specific codes that are not covered in these building code books. NFPA codes extend from NFPA 1 to NFPA 8506 and cover almost any topic for which someone might need a safety code (Andrews, Emily, et al. 2019).

In order to understand the technical aspects presented throughout the industry of fire protection, we conducted research to gain a detailed understanding of several NFPA codes. We describe each of the key codes below, and present findings that are relevant to the Bomberos Laboratory in section 4.4.

2.9.1 NFPA 1 Fire Code

NFPA 1 Fire Code is the leading regulation for building fire safety. NFPA 1 is a code that sets the requirements that are needed to ensure the safety of a building in case of a fire. NFPA states the purpose of the Fire Code is “to prescribe minimum requirements necessary to establish a reasonable level of fire and life safety and property protection from the hazards created by fire, explosion, and dangerous conditions,” (*NFPA 1 Fire Code, 2015 Edition)*. NFPA 1 is applied to all buildings, whether new or existing structures, to make sure that in case of an emergency fire situation all buildings will be able to keep the occupants of the building safe. There are also inspector checklists and tests which accompany the codes. These events happen on a schedule set by NFPA guidelines depending on the type of building that needs to be tested and checked (work building, apartment, rehabilitation center, etc.), the size of the building, and a multitude of other factors. NFPA code also specifies requirements for egress routes depending on the type of building, because different sizes and types buildings require different numbers of egress routes. Understanding NFPA 1 was the basic step to remodeling the existing classroom.

2.9.2 NFPA 45 Standard Fire Protection for Laboratories Using Chemicals

NFPA 45 is a standard code used for laboratories to set up general guidelines and regulations so that all laboratories can be as safe as possible. Since laboratories have a wide variety of uses, such as chemistry, fire protection, and physics, there are many different codes that must be followed. NFPA 45 provides details that apply to a chemistry laboratory such as numbers of egress routes, occupancy codes, and other life safety variables that must be considered when designing a laboratory. There are sections that apply based on the types of experiments that will be performed, the quantity of combustibles in the laboratory, and how chemicals are stored. If there is a possibility of fire or fire experiments, there are additional codes that must be followed. Every area of interest in a laboratory is accounted for in this code.

2.9.3 NFPA 54 National Fuel Gas Code & NFPA 58 Liquified Petroleum Gas Code

NFPA 54 is the National Fuel Gas Code and NFPA 58 is the Liquified Petroleum Gas Code. These codes specify how gas can be transported, stored, and used, as well as outlining piping designs and construction materials. They cover everything from how pipes can be connected to flow rate through different types of valves. They are relevant to the laboratory for the design of gas and air connections to the benches so that the Bomberos can use Bunsen burners and conduct experiments that require gas as fuel.

2.9.4 NFPA 101 Life Safety Code

NFPA 101 standardizes all life safety requirements that are needed for safe egress from a building and general safety of human and animal lives. Similar to NFPA 1, understanding NFPA 101 was a basic step to redesigning a building while maintaining safety standards and means of egress. Means of egress refers to methods of escaping a building during a fire or accident, which is essential to life safety. Unlike NFPA 1, this code book does not deal with fire protection in buildings. Rather than focusing on how the building is protected, NFPA 101 focuses on making sure that the lives of building occupants are protected. The life safety code deals with equipment such as exit signs, emergency lighting, egress routes, spacing around exits, smoke and heat detector placement, and carbon monoxide detectors. Life safety equipment is not equipment used and operated by humans, rather it is in the background of a room or building. Whereas the protective devices that physically act to suppress a fire, such as sprinklers, are regulated by NFPA 1, the life safety equipment regulated by NFPA 101 is used to alert people that there is something wrong in a building or room..

2.9.5 Other Codes

The NFPA codes mentioned above (1, 45, 54, 58, 101) are the most important codes that will apply to the Bomberos laboratory. However, other codes are referenced in those main codes which apply to specific pieces of equipment or aspects of the laboratory. The referenced codes include:

- NFPA 10: Standard for Portable Fire Extinguishers;
- NFPA 13: Standard for the Installation of Sprinkler Systems;
- NFPA 14: Standard for the Installation of Standpipe and Hose Systems;
- NFPA 25: Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems;
- NFPA 30: Flammable and Combustible Liquids Code;
- NFPA 70: National Electric Code;
- NFPA 72: National Fire Alarm and Signaling Code;
- NFPA 80: Standard for Fire Doors and Other Opening Protectives;
- NFPA 90A: Standard for the Installation of Air-Conditioning and Ventilation Systems;
- NFPA 91: Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids;
- NFPA 400: Hazardous Materials Code;
- ANSI/AIHA/ASSE Z9.5-2012: Laboratory Ventilation.

The Bomberos can refer to these in the future based on the kinds of experiments they choose to do in the lab and the equipment they use.

3 Methodology

The goal of our project was to generate a set of designs to remodel an existing classroom at the Academia Nacional de Bomberos into a chemistry laboratory, including proposing the necessary equipment under the budget provided by the Academia. In order to complete the project, we outlined the following project objectives:

1. Clearly define the building safety requirements for a laboratory.
2. Examine models of how other Costa Rican universities have met these requirements.
3. Determine experiments relevant to the ANB and necessary equipment.
4. Determine how to obtain the laboratory equipment under the Academia's budget.
5. Determine the best set of designs for remodeling the classroom into a laboratory.

In order to complete these objectives, we divided each objective into research questions and then used the methods described below to answer them.

3.1 Building Safety Requirements

In order to propose valid laboratory designs, our team first examined the building safety requirements for a laboratory. Costa Rica as recently as 2005 began implementing NFPA codes for university buildings and laboratories. They follow general life safety codes and building codes such as the International Building Code (IBC) and the Uniform Building Code (UBC). On the city level, San José complies with Costa Rica's national guidelines. This means that the general building requirements listed in NFPA, IBC and UBC standards will apply to the ANB buildings with no special amendments.

Our team read through the following codes in order to understand the parameters for the laboratory design. NFPA 1 is the general Fire Code designed to protect lives against fires, along with providing guidelines for suppressing fires in case an accident does occur. NFPA 101 is the general Life Safety Code, which Costa Rica requires building designs to follow. NFPA 13 is commonly used for the installation of fire protection systems, specifically sprinklers and sprinkler systems, with NFPA 25 serving as the Testing and Inspection Checklist for sprinklers and fire protection systems. We also read through specific code used for laboratories, NFPA 45. NFPA 45 is the standard for the Fire Protection of Laboratories Using Chemicals. Other codes were found through further research and are listed in 2.9. As we created designs for the lab, we read over these codes to ensure that the designs would meet safety standards. Key points from the standards are detailed in the Results section below.

3.2 Laboratory Models

The codes above outlined the requirements for a basic university laboratory building. In order to create viable laboratory designs, however, it was helpful to examine models of best practices in laboratory design and use. We therefore studied the chemical and fire protection laboratories at WPI, as well as the chemistry laboratories at the Universidad de Costa Rica and the Instituto Tecnológico de Costa Rica (TEC). The Universidad de Costa Rica (UCR) is the largest and oldest university in Costa Rica, and as such was chosen as a prime example of research laboratories in Costa Rica. TEC is another national institution of higher education that was founded in 1971 and dedicated to research in technology and related sciences to support the development of Costa Rica (TEC, 2020). Both UCR and TEC fall under the same legal and educational requirements as the Academia would, and therefore served as relevant models for laboratory design and practices. Additionally, these laboratories provided information about local safety codes and local vendors for equipment and materials.

The case studies were conducted in person and included a tour of the laboratory followed by an interview with a staff member. The case studies examined the design and usage of a laboratory at a university in order to determine common designs, equipment, and safety procedures. These commonalities could be examined for best practices. Differences between case studies served to demonstrate advantages and disadvantages of certain laboratory designs, depending on the context and goal of the laboratory. All of these were then incorporated into the remodeled classroom design for the Academia’s laboratory.

At each laboratory we explored the following research questions:

1. What are common laboratory designs and what are their advantages and disadvantages?
2. What equipment do other laboratories use? Which is the most essential? How do they procure the equipment and stock chemicals?
3. What safety practices do they use?

Observations from these case studies are presented under Case Studies in the Background chapter above. Based on these observations, our team was able to move forward with generating laboratory designs, contacting local suppliers about equipment and pricing, and researching local laboratory standards and waste disposal methods. These results are detailed in the Results chapter below.

3.3 Laboratory Experiments and Equipment

The case studies above informed us of the chemical equipment used in a general chemistry laboratory. However, it was important to tailor the laboratory to the particular courses and experiments the Academia plans to conduct. Therefore, we researched courses and experiments used by other fire safety and chemical departments to determine what courses and experiments might take place in the laboratory. Experiment descriptions can be found in section 2.6. This information allowed us to propose experiments the Bomberos could conduct in our Recommendations, and to determine whether the laboratory needed additional specific equipment and materials. Combining these equipment requirements into a list for the laboratory, the next step was to determine how to obtain it locally and under budget.

3.4 Budget

The Bomberos initial budget for the laboratory was roughly between 5,000,000 to 8,500,000 colones ($10,000 to $15,000 USD) per year. To meet this budget, our team proposed several lab designs as described in section 3.5 below. The Bomberos were able to choose a design that best fit their academy, as well as to determine how to obtain supplies over time.

Beyond classroom renovation, the budget had to cover laboratory equipment and supplies. Our case studies of various laboratories helped us determine cost estimates and which supplies were essential for the Bomberos lab. We created a list of supplies the laboratory might need to provide to potential suppliers. This list included gloves, protective eye glasses, pipettes, test tubes, beakers, hot plates, balances, fume hoods, and thermometers, among other items. We then contacted supply companies in Costa Rica to determine which companies could source each piece of equipment in what price range.

3.5 Laboratory Designs Over Time

Our case studies described above provided insight into the ways different labs are arranged to serve different functions. We combined aspects from each of the labs we studied into our designs for the Bomberos. Our team then created multiple sets of layouts in order to give the Bomberos a range of options for layouts and equipment over time. The layouts vary in equipment included and the arrangement of equipment in order to give the Bomberos the best possible option. These sets of possible layouts were presented to the chief of the department and other executives to receive feedback. After these meetings we created a final set of laboratory designs based on the feedback. We repeated this process until a final set of designs was chosen that incorporated input from all of the stakeholders and met the requirements for the laboratory.

4 Findings

This section details our findings from our work in Costa Rica. The first section outlines the key points of NFPA standards which apply to the laboratory. Section 4.2 details potential laboratory equipment, suppliers, and prices. Section 4.3 contains laboratory layouts, and Section 4.4 explores the total budget of the Bomberos.

4.1 NFPA Standards

After examining a variety of NFPA manuals, we compiled a list of different features and safety components that must be implemented into the laboratory in order for it to comply with national standards. A summary of NFPA 45, the standard specifically related to laboratories, can be found in Appendix F. Some of the code requirements implemented in our laboratory design were:

- Installing an Air Handling Unit (AHU) in the classroom operating at a rate of 6 or more air changes per hour;
- Installing a second emergency door for egress;
- Removing existing smoke detectors;
- Installing exit signs;
- Installing a sprinkler system;
- Remodeling table setup for proper means of egress;
- Storing gas cylinders outside of the classroom;
- Storing chemicals in specified storage units;
- Installing storage racks for student backpacks and coats outside of the classroom;
- Installing gas connections with manual shut-off valves and an emergency shut-off valve for all connections.

According to NFPA 45, the Bomberos classroom will be an instructional laboratory (a laboratory used for courses beyond the high school level). This designation defines an upper limit on the quantities of hazardous materials which may be stored in the laboratory at one time (see NFPA 45, Table 9.1.1(a) in Appendix F). Additionally, the walls should be fire resistant for a minimum of 1 hour. Further safety recommendations from NFPA 45, such as wearing lab coats, can be found under Laboratory Safety in section 5.6.1. We recommend that the Bomberos refer to the NFPA standards as they construct and run the laboratory, including but not limited to the list of standards in section 2.9.5.

4.2 Laboratory Equipment and Pricing

Based on our discussions with Professor Kmiotek, Director Campos, and Professor Sandoval, our team developed a list of materials and equipment for the laboratory and contacted local suppliers for pricing. We compared the various price points and quality of the equipment to come up with the best value for the Bomberos. With this information, we were able to provide the Bomberos with a list of equipment we believe should be included in the laboratory. The list of equipment covers various basic chemical equipment such as beakers, test tubes, and pipettes, along with more sophisticated equipment like a calorimeter. This list can be found in Appendix G.

4.2.1 Equipment Suppliers

Our team visited the equipment supplier Diprolab after speaking with Director Cristain Campos from UCR. Diprolab is a company with locations all over Central America. This company sells basic laboratory equipment and materials, which the Bomberos will need once they construct the lab. Before our visit, our team developed a list of laboratory materials based on our case studies. Diprolab provided us with prices of each material listed (see prices in Appendix G). Diprolab, however, does not sell large items like fume hoods, so other suppliers are also necessary.

Fisher Scientific is a laboratory supplies and biotechnology company that provides products and equipment internationally. This company sells products that Diprolab cannot provide, such as fume hoods, calorimeters, and safety showers. Furniture, cabinets, and equipment storage can also be bought from Fisher Scientific. Although they sell everything the Bomberos would need to create the chemistry lab, Fisher Scientific's headquarters are located in Waltham, Massachusetts in the United States. Any product shipped to Costa Rica would be comparatively more expensive due to international shipping fees.

4.2.2 Chemicals and Chemical Suppliers

In order to conduct experiments, the ANB needs to purchase chemicals. Our team researched chemical suppliers by inquiring at chemical laboratories and supply stores. We then contacted the companies to determine which companies can be supplied by each supplier and their respective prices. The following are a list of companies which sell chemicals in the area:

- Laboratorios Químicos Arvi
- Tecnodiagnostica
- Fisher Scientific (international)
- Sigma-Aldrich (international)

Based on our case studies, our team created a list of chemicals most commonly used in basic chemistry courses. The list of chemicals, quantities, and prices can be found in Appendix H.

4.2.3 Deionized Water

One substance commonly used in chemistry laboratories is deionized water (DI water). Deionizing water means removing all its ions - such as calcium, fluoride, and chloride - so that they do not interfere with experiments. In order to deionize water, a deionization system passes the water through cation and anion resins, which attract the positive and negative ions respectively and replace them with H+ and OH-, which combine back into water (H_2O) (University of Illinois, 2007). Deionized water is used in laboratories to prepare solutions and clean glassware.

Depending on the experiment, laboratories may also use distilled water. Distilled water has been evaporated and condensed to leave behind residual materials such as salts. DI water requires less time and energy to produce than distilled water, and is therefore often used when distilled water is not required.

There are multiple ways to procure deionized or distilled water for a laboratory. One way is for a laboratory to have a system to produce its own DI or distilled water. The chemistry laboratories at WPI, UCR, and TEC each have their own DI water system. Having their own system is cheaper for these institutions because they serve multiple laboratories and hundreds of students per day, so they need to provide a high volume of DI water. For smaller laboratories, it may be cheaper to purchase DI water from a supplier. The Bomberos plan to begin as a demonstration laboratory and focus on fire-related experiments, which may not require large quantities of pure water. For that reason, we believe that they can begin by purchasing DI or distilled water for laboratory use. The Bomberos can add a deionizing or distillation system to the laboratory if their experiments, course sizes, or other factors requiring distilled water change.

4.2.4 Chemical Waste Disposal

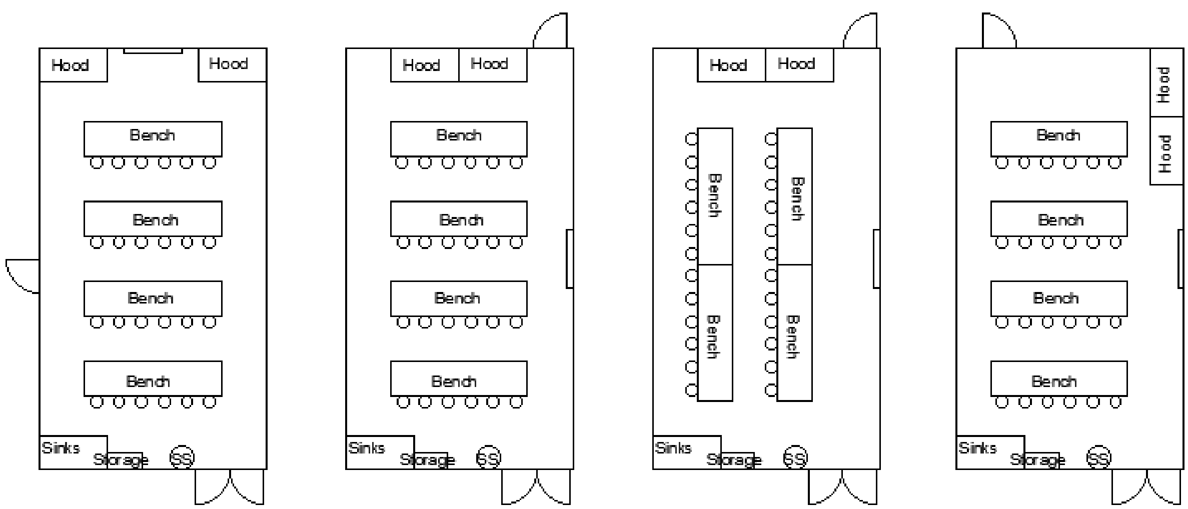
After purchasing and using chemicals for experiments, the Academia will need a method of safely disposing of chemical waste from the new laboratory. Most chemistry laboratories, such as the laboratories at WPI, pay for waste disposal services by volume. Very large operations may benefit from economies by scale by electing to construct and run their own treatment plants. The Academia, however, currently plans to have only one laboratory, which means a very small amount of waste. Therefore, it would cost less for them to dispose of waste through another treatment plant than to construct their own.

After asking local chemistry laboratories how they dispose of waste, our team learned that there are a couple of options. One option would be to use a company to dispose of chemical waste. For example, the TEC laboratories use the cement company Holcim to incinerate their chemical waste. Another option is the University of Costa Rica. UCR is currently constructing its own chemical waste treatment plant which the Bomberos could contract to dispose of waste from the new laboratory. The plant will be finished within the next five months, and will be fully operational by the time the Bomberos laboratory is complete. Contracting with the UCR treatment plant will likely be the easiest way for the Academia to dispose of chemical waste because it is more local and can help build working connections with the university.

4.3 Laboratory Layouts and Timeline

The Bomberos have a timeframe of 5-10 years to renovate and upgrade their laboratory into a fully functioning chemistry and fire safety laboratory. Therefore, our team created a set of designs for the laboratory that the Bomberos can implement over time. Our first step was to create multiple designs and evaluate which layout would work the best. Figure 7 shows our preliminary designs. Each includes four lab benches, enough seating for twenty-four students, two fume hoods, a chemical storage locker, a safety shower and eyewash station, a sink station, and a projector with a SMART Board. We also added an emergency exit door to provide additional means of egress. In each design we ensured that there was enough space to stand up and work around the benches, as well as the hoods without other benches being in the way. Each design also has enough space between the walls and the benches for multiple people to walk by.

Figure 7: Preliminary Designs



These four designs were all ruled out for different reasons. In the first design, on the left, the emergency door cannot be placed on the left side of the building because it opens onto a hill and is an unsafe means of egress in case of emergency. In the second and third designs, the emergency door cannot be placed along the top wall: that placement does not allow enough space for egress between the benches and equipment. Similarly, in the design on the right there is not enough space between the hoods and the benches for a safe means of egress. Lastly, all four designs are missing the small room that currently exists in the bottom left corner, which houses the breaker box and other electrical equipment. At first, we believed that this equipment could be moved or removed, but we were later informed that the boxes must stay where they are and be protected from public access. After discussing the designs above with the Bomberos, we came up with one final design, shown in Recommendations. This design was broken up into five separate designs illustrating a year-by-year progression for five years (Appendix I). The “Year 1” design shows the most crucial and fundamental items the Bomberos must include in the laboratory to allow them to start classes. After this, the rest of the designs slowly add in different pieces of the laboratory to reach the final design.

4.3.1 Systems

Other important aspects of the laboratory to consider were the ventilation, water, sprinkler, electrical, and gas systems.

With respect to ventilation, the existing classroom has an air conditioning unit which cools and recirculates air but does not extract it. Laboratories need to extract air and change all the air in the room over time in order to prevent buildup of gases. The rate of contaminant accumulation over time can be expressed as contaminant outflow subtracted from the sum of the generation rate and contaminant inflow (U.S. Department of Energy, 2014). Generation consists of emissions such as bench-top procedures, contaminant escape from fume hoods, spills, and leaks from bottles and containers. Required ventilation depends on this generation rate and the toxicity of contaminants, where the goal is to keep the contaminant concentrations below the levels of health and fire or explosion concern. The required ventilation rate for the Bomberos laboratory can be determined by engineering analysis; generally laboratories operate at a rate of 6.7 or more air changes per hour while in use (U.S.

Department of Energy, 2014). Installing a ventilation system in the laboratory could consist either of an air handling system or of strong fans in the windows.

The current classroom has no water connection, but water piping runs past the building on the sides by the main door and walkway. The classroom could be connected to this water system in order to provide water for the sinks and emergency shower. This would require creating a piping system within the laboratory to provide and remove the water. Additionally, the water would run to the sprinklers in the ceiling. The classroom currently does not have any sprinklers, but sprinklers are an important safety measure for a laboratory, especially one where fire experiments will frequently be conducted. This means that both sprinkler heads and piping for the sprinklers would need to be installed.

The building currently has electrical connections, but a common laboratory practice is to have electrical outlets at the benches to use for experiments that require electricity or devices such as hot plates. This would require providing electrical wiring that connects to the existing system and then runs along the benches.

Finally, the building does not currently have any gas connections. Creating a gas system would involve putting in gas piping and controls along the benches, and an emergency shut-off valve at the front of the room. Outside of the room, the gas piping would connect to a small storage area where the gas cylinders would be stored. All of the piping and gas construction fall under standards such as NFPA 54 and 58 which the Bomberos and builders can consult to ensure that the actual implementation is safe.

5 Recommendations

Based on the findings in the previous chapter, our team addresses several recommendations to the Bomberos that will allow them to create a chemistry laboratory that best suits the ANB's needs and requirements. Our team has also provided a set of deliverables, including building drawings, that the Bomberos would need to begin constructing the lab.

5.1 Laboratory Layout

Throughout several meetings with the Bomberos, our team provided our sponsor with multiple laboratory designs to renovate the existing classroom at the ANB. The Bomberos chose a final layout that best fit the classroom. As shown in Figures 8, 9, and 10, the final lab design includes:

- Three benches with cabinet storage;
- Twenty-four stools;
- Four sinks;
- Two wall-mounted peg drying racks above two of the sinks;
- Two fume hoods;
- Chemical storage units;
- A safety shower and eyewash station;
- A SMART Board;
- Personal storage units for students' belongings;
- Hooks on the wall for lab coats;
- A desk for the lab instructor.

This layout is designed to be completed over time, given that the Bomberos budget may be limited. The final design is broken up into five stages to help fit within the Bomberos' yearly budget, shown in Appendix I.

Figure 8: Final Design of Laboratory

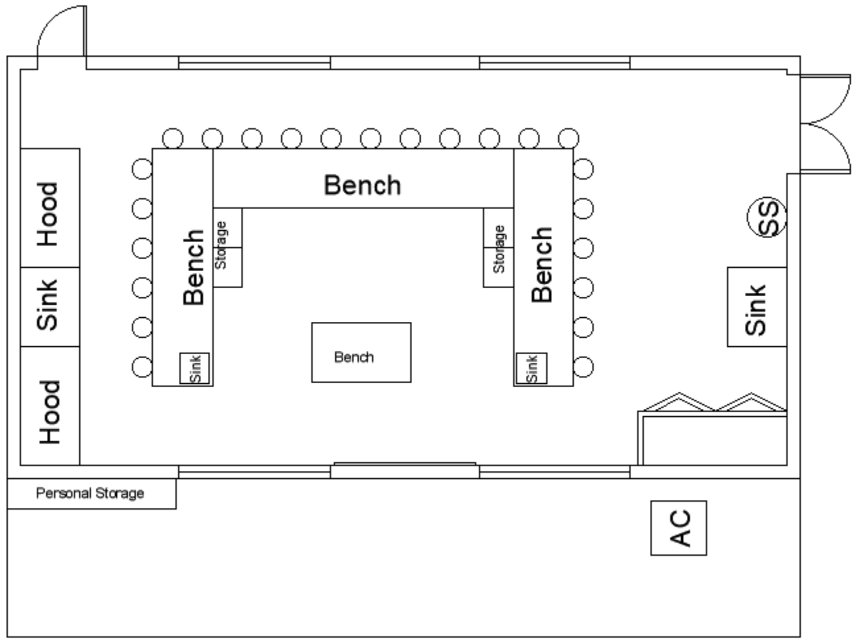


Figure 9: Render 1 of Final Laboratory Design

Figure 10: Render 2 of Final Laboratory

5.1.1 Renovations

To complete the final laboratory design, the existing classroom needs to be renovated. First, a second door needs to be added. This will serve as an emergency exit. Second, the SMART Board and ceiling mounted projector must be moved to the wall behind the teacher's desk instead of the wall opposite of the main double door. Along with moving the projector, the wiring must be redone to allow the professor to connect a computer to the projector from their new desk. Third, gas and water lines must be added to the classroom to help conduct experiments. The water line must connect to all four sinks, the water connections located at each workstation, the emergency shower, the sprinklers, and both fume hoods. The gas lines must reach the gas connections at each workstation as well as both fume hoods. Additionally, the gas line must have an emergency shut-off valve which will shut off all gas connections in the room. See Appendix J for water and gas line design.

Fourth, a new sprinkler system must be installed to help keep the laboratory up to NFPA code. The ANB classroom currently contains smoke detectors but no sprinklers or heat detectors. When examining our case studies, we found that different laboratories have different fire-protection system setups. The TEC laboratories have 68°C heat-activated sprinklers and smoke detectors. The WPI FPE Large Scale Laboratory has 343°C (650°F) heat-activated sprinklers, but no smoke or heat detectors because they typically conduct high-temperature fire experiments where they burn large structures underneath a large cone calorimeter. These experiments emit extremely high temperatures and large amounts of smoke. If there were smoke detectors in this lab, they would be constantly triggered by the experiments performed in the lab. Since the Bomberos plan to conduct fire experiments which may emit heat and smoke, we recommend that they install temperature-activated sprinklers with no additional smoke or heat detectors. However, the classroom already has smoke detectors installed. These can be removed in the future when the Bomberos begin to conduct experiments that emit enough smoke to trigger them.

Lastly, the existing electrical room located in the corner of the room must decrease in size from a 3.7m by 2.3m space (12 foot by 7.5 foot) to a 7.6m by 2.2m space (2.5 foot by 7.25 foot). The electrical boxes will be enclosed by a closet with a folding door to allow for access instead of in their own room.

5.2 Laboratory Equipment and Suppliers

Our recommendations for the basic laboratory equipment and chemicals for the laboratory are described in section 4.2 and can be found in Appendices G and H. For large furniture like the laboratory benches and the personal storage units (Appendix K), we recommend that the Bomberos have these items custom built by a carpenter. This would be less expensive than ordering the items and shipping them to the laboratory.

There are several local and international suppliers from which the Bomberos can purchase their laboratory equipment and chemicals. We recommend that the Bomberos purchase basic equipment and glassware from Diprolab. It would be easy for the Bomberos to obtain equipment from Diprolab because the company is located in San Jose. As a local supplier, Diprolab is also very inexpensive, which is beneficial for the Bomberos with respect to their budget.

Our team recommends that the Bomberos purchase large equipment like fume hoods and calorimeters from an international company such as Fisher Scientific. Most of the large equipment needed in the laboratory cannot be found at local suppliers in Costa Rica, but Fisher Scientific is an international supplier that provides service globally. Although Fisher Scientific is more expensive than other suppliers, their equipment is of high quality and reliable. If the Bomberos can find suppliers for large items such as fume hoods within Costa Rica, however, this will likely be less expensive than using international suppliers.

5.3 Chemicals and Chemical Suppliers

The ANB intends to offer basic chemistry courses in the laboratory. Our team contacted the University of Costa Rica, Technology of Costa Rica, and WPI to see what experiments typically were performed in introductory chemistry lab courses. Gathering information from all of these sources, we came down to a final list of 18 general chemicals that the Academia can obtain to conduct the experiments they want to complete in these courses. Those chemicals are:

- Sodium Hydroxide (NaOH)
- Potassium Hydrogen Phthalate (KHP)
- Deionized Water
- Hydrochloric Acid (HCl)
- Sodium Iodide (KI)
- Sodium Chloride (NaCl or Salt)
- Phenolphthalein (Indicators)
- Potassium Permanganate ($KMnO_4$)
- Iodine
- Acetone
- Potassium Iodate (KIO_3)
- Ethanol
- Toluene

- Gasoline
- Nitric Acid (HNO_3)
- Sulfuric Acid (H_2SO_4)
- Hexane (C_6H_{14})
- Potassium Hydroxide (KOH)

These are the basic chemicals used in experiments for introductory chemistry laboratory classes. Since there are no organic or analytical chemistry courses offered at the Academia, there will likely be little need for more specialized chemicals. If they do need any specialized chemicals, they can purchase them from the chemical suppliers below in acute amounts for desired experiments.

Local suppliers for chemicals include Arvi and Tecnodiagnostica. If the Bomberos want to use an international company, they can also use Fisher Scientific or Merck Scientific. Fisher Scientific is an international chemical and equipment supplier originally stationed in the United States, but now has locations in countries around the world. If the chemicals are safe to ship Fisher is willing to ship them internationally. The prices in Appendix H for the chemicals above are from Fisher Scientific. Merck Scientific is another option of the ANB needs more specialized chemicals.

5.4 Budget & Pricing

The Bomberos have a prospective budget of 6,000,000-8,500,000 Colónes ($10,000-$15,000 USD) yearly to renovate the existing laboratory to the final laboratory design. This budget would include the renovations, furniture, equipment, and supplies the Bomberos will purchase for the lab. To meet this yearly budget, our team broke up the final design plan into a yearly installment plan for up to 5 years. We prepared an estimate for laboratory renovation, one-time equipment purchases, recurring purchases, chemical purchases, and possible future purchases.

The renovations of the classroom will allow the Bomeros to transform an existing classroom into a fully equipped laboratory. The basic renovations of the classroom include adding an air handling system, water and gas piping, some electrical wiring, a sprinkler system, a new door, and an electrical cabinet. We obtained an estimate for the total cost of these renovations from a U.S. contractor. These costs in USD were:

- $1200 for plumbing supplies;
- $700 for electrical supplies
- $600 for concrete and tiles
- $300 for a new door
- $2500 for the AC unit
- $3500 for plumbing work
- $4500 for electrical work
- $900 for breaking the wall to install the new door
- $1500 for AC installation
- $1800 miscellaneous

The total estimated cost for these renovations in the U.S. was 9,700,000 CRCor $17,500 USD. This is likely an overestimate of the cost for the actual laboratory renovations, because materials and labor in the U.S. are much more expensive than in Costa Rica. Actual renovations may cost closer to half of this estimate, but it provides the Bomberos with an idea of a maximum cost of renovation.

Our team next created a list of one-time purchase supplies which will be subject to the initial budget. Some of these supplies include hot plates, balances, Bunsen burners, and lab coats. The furniture such as lab benches, stools, sinks, and storage were also incorporated into one-time equipment costs. The detailed list items, quantities, and costs can be found in Appendix G. This segment of the budget totaled 1,904,810 Colónes ($3,248 USD). However, the prices in the list depend on the supplier. Most items can be purchased locally from Diprolab, while others can be purchased from other companies or built locally. The Bomberos can increase or decrease this cost depending on which companies they purchase from, what quantity of each item they select, and whether they choose to use international suppliers or local carpenters.

Other supplies such as gloves, pipettes, test tubes, and chemicals need to be purchased regularly. A list of 18 chemicals used most commonly for basic chemistry experiments, along with quantities and prices, is in Appendix H. Similarly, a list of prices and suppliers for recurring purchase items can be found in Appendix G. The recurring purchase and chemical purchase budget estimates are 24,000 Colónes ($43.20 USD) and 740,708 Colónes ($1,293.35 USD), respectively. These pertain to initial quantities of chemicals and materials that the Bomberos can purchase to start the laboratory. Over time as the laboratory is used, the Bomberos will learn how often they need to repurchase these supplies. As with the one-time purchase estimate, this estimate depends on the supplier used. The list of chemicals contains prices from Fisher Scientific. If the Bomberos choose to use local suppliers for certain chemicals, they may be able to decrease their costs.

Finally, there is a variety of equipment that the Bomberos can purchase in future years as the laboratory develops. An important possible future purchase is a fume hood. A single fume hood costs approximately 6,000,000 Colónes ($11,000 USD). Due to this high cost, our budget timeline lists the fume hood installments in years 2 and 5 respectively. The costs for other possible future purchases, such as a cone calorimeter and open cup tester, can be found in Appendix G.

In total, the Bomberos can anticipate a budget of about 11,000,000 CRC (21,000 USD) over the first few years. This budget seems feasible, especially with the fluid budget that the Bomberos have. Because many of these prices are based on international suppliers, this is likely an overestimate of the actual cost. Thus, it may be possible to renovate the laboratory in four years, or even sooner. If their budget fluctuates, however, the Bomberos can choose which items are high priority, and which items can be purchased and installed at a later time. The equipment they choose to purchase can be molded to their budget for a given year.

5.5 Experiments

Our team collected experiments used in chemistry and fire safety courses at WPI, UMD, and EKU to recommend to the Bomberos. The following experiments can be performed in a basic chemistry course, similar to that described in Bomberos syllabus:

- Determining volume, mass and density of various objects;
- Determining unknown concentration of NaCl solution;
- Constructing a phase diagram for a solvent mixture;
- Determining concentration of unknown acid solution, unknown iron (II) solution, or unknown Cu(II) solution;
- Stoichiometry of Cu-glycine and Zn-iodine;
- Determining composition of an alloy & ideal gas constant.

We also included a list of fire demonstrations and experiments in the deliverables we provided the Bomberos, including:

- Demonstrating basic fire concepts with candles;
- Determining the flash points for various materials;
- Examining various methods of ignition.

We further recommend that the Bomberos explore the experiments described in the ASTM standards and in the Carmody Trainer. These experiments range from simple to complex. They can be used by the Bomberos as they are provided or to generate ideas for new demonstrations.

5.6 Laboratory Safety

Most chemistry laboratories follow the same standard safety procedures. Our team researched safety standards provided by the American Chemical Society (ACS), the National Institutes of Health (NIH), the Occupational Health and Safety Administration (OSHA), and the

NFPA, among others, in order to provide the Bomberos with recommendations for laboratory safety practices (ACS, 2016; NFPA, 2019; NIH, n.d.; OSHA, 2011; ThermoFisher Scientific, n.d.). Below is a list of proposed lab safety techniques that consist of personal techniques, procedure techniques, and emergency planning techniques.

5.6.1 Personal Safety

All students and instructors who utilize the laboratory should follow personal safety guidelines in order to minimize risk. Everyone who enters the lab should be informed of these guidelines. In order to increase personal safety and minimize risk, all laboratory occupants should:

- Wear long pants and closed-toed shoes.
- Tie back long hair, jewelry, and anything that may catch in equipment.
- Wear lab coats and safety glasses any time an experiment will be conducted.
- Wash hands after working with chemicals and before leaving the laboratory.
- Avoid eating, drinking, and handling contact lenses while in the laboratory.

These personal safety precautions are important yet easy to follow. Wearing gloves, keeping aisles clear, working with a partner, and knowing how to use the safety shower and eyewash station in case of an emergency are simple procedures that can keep people safe. One of the most important procedures in a chemistry laboratory is wearing the proper clothing. In all laboratories it is required that those in the lab wear long pants, closed toe shoes, gloves, and lab coats. These articles of clothing provide protection against acids or other harmful chemicals that could come into contact with skin. They also provide a layer of protection that can be removed in case of an emergency, and will allow time for a person to react before the chemicals reach the skin. Tying hair back during laboratory experiments is also important. For example, when a person is working with experiments that require open flames, long hair needs to be tied back so there is no possibility that it will catch fire. Also, if working with a petri dish or other open chemical experiments, long hair could become coated in the chemicals and potentially cause damage to hair or skin.

Another crucial point of laboratory safety is not eating or drinking in the laboratory. For some chemicals like acetone, it is possible for the chemical to come into contact with skin without harm, but if ingested these chemicals can upset or damage the stomach and intestines. Loose drops of chemicals can accidently fall into any food or drink present in the laboratory, and if people then ingest these chemicals they may become ill and possibly die. It is also possible that the food or drink can fall into and disrupt an experiment. That is why this is the one of the most important personal safety rules, as many of the chemicals used in introductory laboratory classes are not typically corrosive or dangerous when they come into contact with a person, but they are much more dangerous when ingested.

5.6.2 Laboratory Procedures

General and experiment-specific laboratory procedures help ensure that the laboratory and persons stay clean, safe and organized in order to minimize the possibility of accidents. Here is a list of procedures, with some additional explanations below:

- Wearing gloves during an experiment.
- Disposing of sharps in the provided safety container.
- Cleaning laboratory equipment regularly with appropriate disinfectant.
- Understanding the chemicals used in each experiment, their possible dangers, how to deal with emergencies, and how to dispose of them, such as by understanding a Material Safety Data Sheet (MSDS).
- Labeling storage containers with the chemicals they contain and the date.
- Labeling waste containers with the chemicals that are safe to be placed inside of the waste container and disposing of chemicals in designated disposal containers.
- Knowing how to use the safety shower and eyewash station in case of emergency.
- Using the safety shower and eyewash in emergency situations and reporting it.
- Always working with at least one partner.

- Using fume hoods for experiments with acids, corrosives, and other high-risk elements.
- Keeping aisles clear.
- Monitoring experiments constantly, especially those involving reactions and heat.

Wearing gloves protects experimenters' hands from chemicals and possible spills.

Disposing of sharp objects such as broken glass in the specified container, as well as making sure that no sharp objects are disposed of in a trash bag, helps to make sure that nobody is cut or pricked by accident. Disposing of sharp objects in the specified container also helps to make sure that a trash bag doesn't rip or break, exposing potential hazardous materials to the environment around it.

It is also important to properly clean the equipment used in experiments. The first step in cleaning laboratory equipment is disposing of the used chemicals. In some cases the chemicals are harmless and can be dumped in the sink, but in other cases the chemicals need to be disposed of in separate containers. After the chemicals are disposed of it is important to properly disinfect the equipment to ensure that there is no chemical residue left on the equipment. This can generally be accomplished by rinsing the equipment with acetone. If equipment is not cleaned properly, there is a possibility for there to be an unwanted reaction the next time that the equipment is used.

Labeling of storage containers with the chemicals they contain and the date that the chemicals were put into a container helps experimenters know what they are working with, as well as how volatile or dilute a chemical is. Different chemicals become diluted over time and lose their reactivity; on the other hand, some become volatile and could explode if not handled properly. In a chemistry laboratory it is also important to label the waste containers. Labeling waste containers ensures that unwanted chemical reactions are not created when waste products of experiments are placed into the same container. Waste containers need to be specially marked with what chemicals are allowed to be mixed together without creating a reaction, whether that reaction is an explosion, fire, or the creation of harmful gases. After experiments are done, students must look at the labeled waste containers to put their waste into the proper container so that these types of accidents do not occur. Waste chemicals can be stored in plastic bottles, except where incompatible. Often these bottles can be the bottles the chemicals were delivered in. As above, waste containers should be labeled with the chemical or chemicals they contain and the date of waste generation. Chemicals should be segregated by compatibility into groups such as acids, bases, flammables, oxidizers, and water reactives. Groups should be separated by a non-combustible partition, e.g. on a separate shelf or cabinet (UC Berkeley, n.d.).

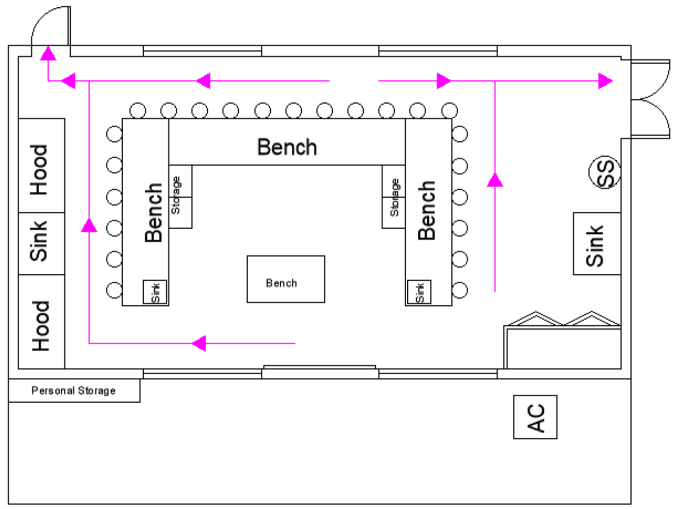
Knowing when to use a fume hood is an important concept when working in a chemistry laboratory. A fume hood is used when there is a possibility that the experiment can expel harmful gasses or smoke. The fume hood contains the experiment, with the glass windows on the front allowing students to see the experiment, while ventilation at the top of the fume hood safely releases the gasses or smoke and protects those conducting the experiment. Fume hoods allow students to perform experiments that typically could not be performed in an open classroom in the absence of a means to control the fumes.

5.6.3 Emergency Plans

In case of emergencies, every building requires egress (exit) plans so that occupants will be aware of the safest way to escape the building or room. Typically, buildings have multiple means of egress depending on the building's size, the number of doors that the building or room has, and occupancy codes. For people to be able to safely escape in case of an emergency, they must:

- Know means of egress maps (See Figure 11).
- Make sure all fire protection equipment is working.
- In case of an earthquake, know general safety guidelines.
- Know how to use all safety equipment.

Figure 11: Plan of Egress



5.6.4 Fire Protection and Life Safety Upgrades

The existing classroom has fire protection and life safety systems that are necessary and up to code. There are two smoke detectors in the classroom, a smoke detector in the closet, a light and speaker strobe, and one set of emergency lights in the classroom. There is no exit sign above the existing door, nor a sprinkler system. In order to convert the room into a chemical and fire laboratory, we needed to adjust the fire protection system. We recommend removing the two smoke detectors in the classroom, as fire experiments performed in the classroom could easily set them off. We further propose moving the existing smoke detector in the electrical closet from its current position to in between the electrical boxes. Its current position would be outside of the new cabinet and would not be able to detect issues with the electrical boxes. We also recommended keeping the speaker strobe in its existing position, as well as the existing emergency lighting. Based on our case studies of other laboratories, we decided that the best form of fire protection would be the addition of a sprinkler system to the classroom. The sprinkler and fire protection plan can be found in Appendix L. We also recommend minor life safety upgrades, including exit signs above both the main door and the new emergency door. In addition, we added in two more emergency sets of lights on either side of the classroom. This plan is also in Appendix L.

6 Conclusion

The goal of our project was to convert an existing classroom into a chemistry and fire protection laboratory for the Academia Nacional de Bomberos. This laboratory will allow the Academia to conduct the chemistry and fire safety courses needed to offer degrees in fire safety. Offering these degrees will allow them to become a parauniversitaria. This project included an investigation of NFPA code books, several case studies of university laboratories, and multiple interviews and discussions to fully understand the details necessary to create a laboratory. After completing the above actions, our team developed a 5-year plan to allow the Bomberos to complete the laboratory while keeping their spending under a restricted yearly budget. This plan included an emergency egress floor plan and a remodeled fire protection and life safety plan for the laboratory. We also gave the Bomberos a detailed list of equipment and chemicals that they will need for the laboratory. In this list, we included locations, prices, and suppliers for each piece of equipment and chemical. The Bomberos also asked for suggestions of experiments for their courses based on their chemistry syllabus. We contacted several other universities to see what experiments are performed in introductory chemistry and fire safety courses, which aided us in compiling a list of experiments for the Bomberos.

After developing the laboratory design in accordance with Bomberos' requirements, our project team hopes that with the help of our design the Bomberos can create a laboratory and become a certified parauniversitaria. We hope that our project will help to provide the Bomberos with years of successful chemistry and fire protection experiments.

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Appendix A

Cost Comparison for Education in Costa Rica and the United States

At the University of Costa Rica, which is the largest public school in Costa Rica, tuition for undergraduates runs around 1,595,000 Costa Rican Colónes (CRC) per year, or 2800 USD (CostaRica.com., 2020). By comparison, the average cost to attend college in the United States is 7000 USD per semester, or 3,987,000 CRC. Median household income in the U.S. is 56,516 USD annually (United States Census Bureau, 2016). Average household income in Costa Rica is around 13,761,000 CRC (24,160 USD), about 43% of the average U.S. household income (Tico Times, 2018). Per semester, that's 11% of income in Costa Rica versus 12% of average household income in the U.S. Thus, although the raw tuitions differ, the perfect of income they represent are almost identical.

Appendix B

List of Questions for UCR and TEC chemistry laboratories

- From what companies do you purchase chemicals and laboratory equipment?
- How do you store chemicals and chemical waste?
- How do you dispose of chemical waste?
- What chemicals do you use for basic chemistry courses?
- What form of ventilation (AC, fans, etc) does the laboratory use?
- Does the laboratory distill its own water?
- How many students use the laboratory at once?
- Does the laboratory have gas and air connections at each lab bench? What experiments are they used for?
- What experiments are the fume hoods used for?
- Does the laboratory have heat or smoke detectors?

Appendix C

ANB Chemistry Syllabus

DGO-10 Química FALTA BIBLIOGRAFIA

INSTITUCION	ACADEMIA NACIONAL DE BOMBEROS
CARRERA	DIPLOMADO EN CIENCIAS DEL FUEGO: GESTION OPERATIVA
Nombre del curso	Química
Código	DGO-10
Créditos	3
Requisitos	DGO-04
Correquisitos	N/A
Modalidad	Cuatrimestral
Naturaleza	Teórico-Práctico
Nivel	II Ciclo
Duración	Quince semanas lectivas de 2 horas presenciales, 2 horas de práctica y 5 horas trabajo independiente
Horario	Martes de 18:00 a 22:00
Aula	A32
Profesor	

DESCRIPCIÓN

La asignatura de Química es el estudio de la materia y sus interacciones con otras energías y materias; es importante su estudio porque ayuda a comprender muchos fenómenos de la Naturaleza y de las relaciones con los cambios físicos y químicos que ocurren en los tres estados de la materia.

Los estudiantes conocerán las concepciones básicas en relación a la teoría del fuego, a fin de comprender las bases que la sustentan y los diferentes enfoques en la teoría del fuego que puedan garantizar un ejercicio de la profesión desde la integralidad.

Se dan los principios de la materia y sus transformaciones y los compuestos químicos par entender lo que le ocurre a una sustancia cuando cambia de un tipo de materia a otro. Este cambio químico a menudo involucra una reacción de dos o más sustancias para formar otros tipos de compuestos. Se identifican los peligros y la seguridad que debe tener el bombero ante ciertos compuestos químicos y se estudiará la teoría del fuego.

Acorde con el perfil profesional se estudiarán los conocimientos básicos en química identificando los elementos y los compuestos que componen la materia para resolver ejercicios, así como los principios de la teoría del fuego.

Este curso del área de ciencias básicas es teórico-práctico y responde según el perfil profesional a la siguiente pregunta: ¿Cómo aplicar los conceptos básicos de la química identificando los elementos y los compuestos inorgánicos y orgánicos que componen la materia, considerando la dinámica y evolución de los incendios?

Para responder a esta interrogante se estudiarán los siguientes conocimientos:

- Materia y transformaciones químicas
- Compuestos químicos
- Identificación de peligros y seguridad ante ciertos compuestos químicos
- Termoquímica
- Compuestos orgánicos
- Teoría del fuego

A lo largo del curso se promoverán las siguientes habilidades:

- Capacidad para sistematizar conceptos básicos de química y sus interacciones.
- Capacidad para la clasificación de las sustancias dañinas para el ambiente, líquidos o sólidos inflamables, gases, explosivas, sustancias tóxicas e infecciosas.
- Capacidad para reconocer los fenómenos asociados al proceso de combustión.

- Capacidad para aplicar conocimientos de química en la resolución de problemas relacionados con la combustión.

Entre los valores y actitudes que se fomentarán entre los estudiantes se ubican las siguientes:

- Interés por aprender a aprender
- Pensamiento sistémico
- Trabajo en equipo y liderazgo
- Interés por resolver problemas
- Inteligencia para mejorar procesos y proponer soluciones

COMPETENCIAS, CRITERIOS Y EVIDENCIAS

Las competencias para la Academia Nacional de Bomberos son acciones reflexivas e integrales que responden al perfil profesional y a los problemas del contexto, con idoneidad y compromiso ético, integrando el saber ser, el saber hacer y el saber conocer en una perspectiva de mejora.
A continuación, se presentan tanto las competencias disciplinares como las generales, ligadas a sus criterios y evidencias de desempeño para este curso.

Tipo de Competencias	Criterios de desempeño (Sub-competencias)	Evidencias del desempeño
Disciplinar Aplica los conceptos básicos de la química identificando los elementos y los compuestos inorgánicos y orgánicos que componen la materia, considerando la dinámica y evolución de los incendios	Practica los conceptos básicos de química utilizando las propiedades de los elementos. Practica las fórmulas químicas utilizado los principios de las reacciones químicas. Aplica los principios de la teoría del fuego considerando los fenómenos asociados al proceso de combustión.	Resultados de las prácticas de laboratorio. Informes de lecturas Mapas mentales Pruebas de ejecución
1.Competencia cognitiva En esta competencia, el pensamiento debe ser sistémico y crítico dentro de la búsqueda de aprender a aprender y crecer como bombero. Está íntimamente relacionado con el proceso de adquisición del conocimiento para su posterior praxis en el ejercicio de aprender a conocer y las formas de pensar. Busca la comprensión, innovación, creatividad y resolución de problemas.	Aprender a aprender, actualizando el saber de manera continua a lo largo de la vida considerando el desenvolvimiento eficaz en la sociedad del conocimiento.	Análisis de casos utilizando la teoría del fuego
2.Competencia operativa: se busca ser un ciudadano global con responsabilidad social e individual. Desarrollar sus capacidades cuerpo y mente,	Da lo mejor de sí en todo lo que hace (aprender a ser), de la mano con su crecimiento personal, con	Prácticas propias de su quehacer bomberil y de autocuidado en uso de químicos

inteligencia y sensibilidad en armonía con su entorno (formas de vivir en el mundo), pues su quehacer bomberil salva vidas; por ello, da lo mejor de sí en todo lo que hace (aprender a ser), de la mano con su crecimiento personal, con prácticas de autocuidado y con proyección social.	prácticas de autocuidado y con proyección social.	
3. Competencia comunicativa: se relaciona indisociablemente con el aprender a vivir juntos, comunicarse y relacionarse con otros, así como ser parte de las diferentes interacciones humanas. Se busca transmitir mensajes claros y concretos en el acto comunicativo, esto no solo refuerza las relaciones interpersonales sino que colabora en la **efectividad del trabajo en equipo** y busca el mejor resultado de las tareas bomberiles.	Comunicar pensamientos disciplinares en forma oral, visual y escrita en forma clara y concreta sea en forma individual o en el trabajo en equipo.	Participación en discusiones grupales, exposición de trabajos individuales o en grupo.
4. Competencia actitudinal-afectiva: aprender a ser de manera que se integre al mundo y reconozca la influencia que puede ejercer sobre su entorno, la responsabilidad de su aprendizaje, sus acciones y las relaciones que establece con los demás. Consciente de que en la era digital el acceso a la información es fácil, pero debe reflexionar acerca de ella y no dejar de lado las interacciones efectivas y asertivas en la relación con los otros.	Relacionarse bien con otros. Manejar y resolver conflictos. Negociar sabiendo inspirar confianza y empatía.	Integra los conocimientos, habilidades y actitudes necesarias para aplicar con responsabilidad su aprendizaje en el quehacer de bomberos y aplicar las técnicas de comunicación interpersonal efectivas y asertivas.

CONTENIDOS

1. Tema: Materia y transformaciones químicas

- Estructura atómica de la materia.
- Masas atómicas y moleculares. Concepto de mol
- Clasificación de las sustancias: dañinas para el ambiente, líquidos o sólidos inflamables, gases, explosivas, sustancias tóxicas e infecciosas.
- Propiedades de las disoluciones

2. Tema: Compuestos químicos

- Moléculas y fórmulas químicas
- Propiedades de los compuestos químicos: iónicos, metálicos, moleculares y sustancias cristalinas

- Reacciones químicas: Clasificación de las reacciones químicas
- Leyes de las reacciones químicas
- Cálculos estequiométricos

3. **Tema: Identificación de peligros y seguridad ante ciertos compuestos químicos**
   - Tipos de compuestos químicos presentes en los incendios.
   - Comportamiento de los compuestos químicos en los incendios.
   - Seguridad ante productos químicos dañinos a la salud.

4. **Tema: Termoquímica**
   - Procesos termoquímicos
   - Entalpía: Entalpía de formación y Ley de Hess
   - Entropía y segunda ley de Termodinámica.
   - Calor de combustión

5. **Tema: Compuestos orgánicos**
   - Concepto de compuestos orgánicos
   - Hidrocarburos: lineales y cíclicos y aromáticos
   - Grupos funcionales que contienen oxigeno: Alcoholes y fenoles, Aldehídos y Cetonas, Ácidos carboxílicos, Ésteres, Éteres
   - Grupos funcionales que contienen nitrógeno: Aminas; Amidas; Nitrocompuestos y Nitrilos
   - Grupos funcionales que contienen halógenos

6. **Tema: Teoría del fuego**
   - Concepto.
   - Combustión: El tetraedro del fuego; Combustible; Densidad; Limites de inflamabilidad; Temperatura de inflación y autoignición.
   - Carburante
   - Reacción en cadena
   - Velocidad de combustión
   - Clasificación de los fuegos: (A, B, C, D y K)
   - Dinámica y evolución de los incendios
   - Explosiones: químicas y físicas en líquidos inflamables y combustibles
   - Fenómenos asociados al proceso de combustión:
     - Explosiones (BLEVE); Rebosamiento violento por ebullición (*Boil over*); rebosamiento superficial *(slop over),* rebosamiento espumoso *(froth over)*
     - *Flame over*, bola de fuego *(Fire ball),* combustión súbita (*flash over)*
     - Explosión de flujo reverso.
     - Explosiones de vapor no confinadas (UVCE)

METODOLOGÍA

Cada una de las secciones del curso está compuesta por una parte teórica y una parte práctica, que permite entender los principales conceptos de la química y sus aplicaciones y que servirán como base para cursos más avanzados en la carrera.

La parte teórica se dará mediante conferencias de parte del docente, lecturas dirigidas de capítulos de libros y análisis y discusión de artículos científicos de actualidad. La parte práctica se hará por medio de práctica de laboratorio y demostraciones o resolución de problemas en clase.

Al ser un curso donde se busca la utilización de los conceptos de la química para analizar y proponer soluciones a problemas de la combustión, se emplea la metodología de Aprendizaje Basado en Problemas (APB) donde el estudiante se enfrenta a las principales causas de las explosiones y propone posibles soluciones a problemas reales concretos.

Su finalidad es formar estudiantes capaces de analizar y enfrentarse a los problemas de la misma manera en que lo hará durante su actividad profesional, que los conducirá a la adquisición de competencias profesionales.

El papel del docente consiste en ser mediador, facilitador y orientador del proceso de enseñanza y aprendizaje. La participación de los estudiantes durante el curso será de gran importancia para el logro de las competencias propuestas.

Appendix D

UMD FPE Course Syllabus Excerpts

ENFP 420	Fire Assessment Methods and Laboratory	Spring 2020

SYLLABUS

Course Summary

Experimental evaluation of ignition, flame spread, rate of heat release and smoke production of flammable gases, liquids, solids, and interior finish materials. Analytical and computer methods for the design, performance, and analysis of fire experiments. Preparation of laboratory reports.
4 credits

Lab 1: Cleveland Open Cup – ASTM D92
Lab 2: Smoke Chamber – ASTM E662
Lab 3: Cone Calorimeter – ASTM E1354
Lab 4: Cup Burner – NFPA2001 Annex B
Lab 5: LIFT – ASTM E1321

Appendix E

EKU Experiment Protocol

FSE 120 Laboratory Safety Protocol – Flammability Range Experiments

TABLE 1: EXPERIMENT INFORMATION

Experiment title: Flammability Range Experiments		
Course: FSE 120 Fire Behavior and Combustion		
Protocol Number: FSE120-002	**Revision**: 001	**Date**: January 7, 2016

1.0 BRIEF DESCRIPTION OF ACTIVITY

1.1 This demonstration involves students watching the Instructor of Record (IOR) demonstrate that the air-vapor ratio for a given fuel must be within its flammability range before it will undergo combustion. This experiment utilizes a small metal tube and rubber stopper for demonstration of small explosion. The experiment is conducted in the Fire Protection and Safety Laboratory – chemistry lab classroom.

1.2 The term "flammability range" relates to the air-fuel or air-vapor mixture required for ignition. The term "explosion" means nothing more than combustion occurring in a confined space.

2.0 PURPOSE

2.1 The purpose of this document is to describe the safety protocol for the flammability range experiments.

2.2 This experiment will assist students with the learning objective for the FSE 120 course, specifically to "*The student will correctly use terms and concepts associated with the chemistry and physics when describing fire and fire development.*" and "*The student will describe applications of the principles associated with fire dynamics to fire protection, suppression and investigation issues*".

3.0 SCOPE

3.1 This document applies to the following individuals:

3.1.1 FSE 120 Instructor of record (IOR)

3.1.2 FSE laboratory coordinator

3.1.3 any participating graduate assistants

3.1.4 any participating laboratory employees

3.1.5 FSE program coordinators

3.1.6 any students enrolled in the FSE 120 course.

3.1.7 any observer present in the location of the experiment.

3.2 This document applies to the FSE 120 Flammability Range Experiments

4.0 RESPONSIBILITIES

4.1 The IOR is responsible for ensuring that the students receive the appropriate instruction and materials for the experiment.

4.2 The IOR is responsible for the safety of the students before, during, and after the lab activity.

4.3 The FSE laboratory coordinator is responsible for ensuring that the laboratory facilities used by the students are working properly and the outlined safety equipment is available for IOR and student use.

4.4 The FSE program coordinator(s) and other interested faculty members are responsible for reviewing this document and approving it based upon the recommendations of the IOR, who has designed the experiment and authored the document.

5.0 DEFINITIONS

5.1 Acronyms / abbreviations

5.1.1 EKU – Eastern Kentucky University

5.1.2 FPPS – Fire Protection and Paramedicine Sciences

5.1.3 GA – Graduate Assistant

5.1.4 IOR – Instructor of Record

5.1.5 SDS – Safety Data Sheet

5.1.6 NFPA – National Fire Protection Association

5.1.7 OSHA – Occupational Safety and Health Administration

5.1.8 PPE – personal protective equipment

5.1.9 SOP – standard operating procedure

6.0 HEALTH AND SAFETY WARNINGS

6.1 Appropriate PPE is required including:

6.1.1 All participants and observers will wear safety glasses and be situated behind the marked safety line.

6.1.2 The IOR and lab coordinator will be wearing fire resistant gloves, fire resistant lab coat or equivalent, safety glasses, closed-toed shoes, and long pants.

7.0 SAFETY SUPPLIES AND MATERIALS

7.1 Safety glasses for all participants

7.2 Fire resistant lab coat or equivalent for the IOR and lab coordinator

7.3 Fire resistant gloves for the IOR and lab coordinator

7.4 A NFPA 10 compliant dry chemical or CO_2 fire extinguisher.

7.5 Spray bottle filled with water.

7.6 A switched extension cord for remote disconnect for high-voltage power supply.

7.7 Lab equipment policy form filed with the FSE lab coordinator.

8.0 PROCEDURES FOR NORMAL EXPERIMENT OPERATION

8.1 A time for the lab to occur will be arranged by the IOR with the FSE lab coordinator through the lab equipment use policy.

8.2 The laboratory area will be setup by the IOR with the help of the lab coordinator and available GA's before the class begins. The following actions are required for setup:

8.2.1 A safe area for students to observe the experiment will be marked off 6ft radius from the experimental area (per NFPA 45). This hazardous zone will be marked off using a yellow identifier (per OSHA 1910.144).

8.2.2 Personal protective equipment is to be brought to lab area.

8.2.3 Extinguishing equipment is to be brought into the lab area

8.2.4 A switched extension cord for remote disconnect for high-voltage power supply will be required for this demonstration. The lab coordinator or GA will be located at the switch to disconnect in the event of any identified electrical hazards.

8.3 A safety briefing will be held with students before the experiment begins per NFPA 45 section 12.3.2.3.

8.4 After the IOR is ready to begin the demonstration, the students will be asked to remain behind the marked safety line (Appendix B).

8.5 Students will be instructed to follow along with the IOR through the laboratory procedures (Appendix A).

8.6 After all of tests are completed the IOR with the help of the lab coordinator and available GA's will clean up the laboratory area.

8.7 The IOR, available GA's, and the FSE Lab Coordinator will replace equipment and materials used in the lab after the experiment.

9.0 EMERGENCY PROCEDURES

9.1 In the event of an emergency in the Ashland Building the participants will follow the Ashland Building Emergency Action Plan.

9.2 In the event of an emergency on campus the participants will follow the EKU Richmond Campus Emergency Action Plan.

9.3 In the event of an unintentional fire the Ashland Building Emergency Action Plan is to be followed.

9.4 In the event of a medical emergency the Ashland Building Emergency Action Plan is to be followed.

9.5 In the event that the fume hood stops working, the laboratory work will be shutdown immediately and the lab area will be evacuated.

9.6 In the event emergency communication by phone is required the following numbers can be used:

9.6.1	Local Emergency service:	911
9.6.2	EKU police:	(859) 622-1111
9.6.3	Kentucky State Police:	(859) 623-2404
9.6.4	Baptist Health Hospital:	(859) 625-3999

10.0 SAFE AND HAZARD ZONES FOR THE ACTIVITY

10.1 The hazardous zone for this demonstration is identified by the 6 feet radius from the edge of the demonstration table as shown in Appendix B.

10.1.1 This zone will be outlined with a yellow identifier on the floor or through barricade tape.

10.2 Once the demonstration begins, only the IOR and lab coordinator with appropriate PPE are allowed into this hazardous zone. No student or guest is allowed beyond this marked safety zone after the demonstration has begun.

10.3 All personnel entering this hazardous zone will wear safety glasses, a long sleeve fire resistant lab coat or equivalent, gloves, long pants, and closed toed shoes.

10.4 The students watching the demonstration will have safety glasses on and will remain outside of the hazardous zone.

FSE 120 Laboratory Safety Protocol – Flammability Range Experiments

11.0 PROTOCOL ON HANDLING FUELS

11.1 Gasoline will be used with these experiments (Appendix D). Only a small volume of gasoline is required for this demonstration. Therefore, a compliant ignitable liquid container filled to no more than 100 mL will be brought into the hazardous zone for the demonstration.

11.1.1 Any extra fuel in the room is prohibited per NFPA 45, NFPA 30, and OSHA 1910.106.

11.2 An eyedropper will be used to remove the appropriate quantity of gasoline for the demonstration. The container with the remaining gasoline will be closed and moved to the opposite end of the demonstration table.

12.0 SUPPRESSION

12.1 When ignition does occur, there should not be any residual combustion within the tube. However, in the event that combustion does continue the IOR will use the metal cover to occlude oxygen from entering the tube.

12.1.1 Should any class A fuels become involved a spray bottle filled with water will also be present.

12.2 Two suppression personnel are required for this experiment. These are to be the IOR and the FSE Laboratory Coordinator (or approved replacement).

12.3 Secondary suppression will be done with a dry chemical, or CO_2 extinguisher per the requirements of NFPA 10 by the FSE Laboratory Coordinator (or approved replacement) if needed.

13.0 REPORTING AND DOCUMENTATION

13.1 Scheduling of the experiment is to be done with the FSE lab coordinator and FSE coordinators. Material will be requested using the standard FSE Laboratory Equipment Policy form.

13.2 Completed experiment documents are to be uploaded on blackboard by students or handed in depending on the IOR instructions.

13.3 Any injury incident reports are given to the FSE laboratory coordinator.

13.4 Any damaged equipment is to be reported to the FSE laboratory coordinator.

13.5 Any consumable materials that need to be replaced are to be reported to the FSE laboratory coordinator.

14.0 REFERENCES

14.1 EKU Laboratory Safety Policy

14.2 OSHA Laboratory Safety Guidance

14.3 OSHA 1910.132 – Personal Protective Equipment – General Requirements

14.4 OSHA 1910.133 – Eye and Face protection – Personal Protective Equipment

14.5 OSHA 1910.138 – Hand Protection – Personal Protective Equipment

14.6 OSHA 1910.157 Portable Fire Extinguishers – Fire Protection

14.7 OSHA 1910.1200 – Hazard Communication – Toxic and Hazardous Substances

14.8 NFPA 10 – Standard for Portable Fire Extinguishers

14.9 NFPA 45 – Standard on Fire Protection for Laboratories Using Chemicals
14.10 Ashland Building Emergency Action Plan
14.11 EKU Emergency Action Plan

15.0 ATTACHMENTS, FORMS, CHECKLISTS

15.1 Appendix A: Procedures for this experiment
15.2 Appendix B: Applicable Diagrams
15.3 Appendix C: Applicable Hazard Calculations – N/A
15.4 Appendix D: SDS for applicable hazardous materials being used in experiment

16.0 REVIEWS AND REVISIONS

16.1 The document is to be reviewed by the IOR before each time the experiment is conducted. If any significant changes are made to the experiment this protocol must be reapproved. Changes to the document are to be recorded using track changes and submitted to the FSE program coordinators.

16.2 Author and approval signatures are located in Table 2.

TABLE 2: APPROVAL SIGNATURES

	Signature	Job Title	Date
This document was written by:	[signature]	Assoc. Prof.	1/20/16
This document was reviewed by:	[signature]	Lab Coordinator	1/20/16
This document was approved by:	[signature]	FPSET Cord	1-20-16

17.0 REFERENCES

17.1 Dr. Scott Rockwell developed the general format and outline for this laboratory safety protocol.

Appendix A: Laboratory Procedures

Below are simple procedures, please see the Carmody Combustible Hazards Trainer manual for more detail if needed.

Objectives:

1. To demonstrate that explosion is combustion in a confined space.
2. To demonstrate that the air-vapor ratio for a given fuel must be within its flammability range before it will burn or explode.

Materials:

1. Power supply
2. High-voltage connecting leads
3. Spark plug ignition chamber
4. Rubber stopper
5. Length of small chain
6. Eyedropper
7. Large metal cover with handle
8. Gasoline- a compliant ignitable liquid container filled to no more than 100 mL will be brought into the hazardous zone for the demonstration.

WARNING

High Voltage

5000V

1. Be sure high voltage is off when connecting leads.
2. Turn high voltage off immediately after demonstration.
3. Do not touch spark plug ignition chamber while high voltage is on.

Procedure:

1. Place two or three drops (no more) of gasoline in the chamber along with the length of chain.
2. Cork the tube with the rubber stopper and shake the entire assembly briskly to ensure vaporization of the gasoline.
3. Hold the large cover 8-10 inches above the rubber stopper and turn the high-voltage switch ON. A small explosion will occur.
4. Blow the residual products of combustion from the first explosion from the tube and repeat the demonstration, using six drops of gasoline. Under normal circumstances, no explosion will occur. (Actuate the high-voltage switch several times to positively establish that current is being applied to the spark plug.)

Appendix A: Laboratory Procedures

5. Turn off the high voltage and remove the connecting wires. Then remove the cork from the tube and invert the tube for a few seconds. Reinsert the cork, reassemble the equipment, and again actuate the high-voltage switch.

6. Normally, a sufficient amount of gasoline vapors will have fallen from the tube when it was inverted to adjust the air-vapor mixture in the tube to the combustible range of gasoline. If an explosion does not occur, empty more vapor from the tube and try again.

7. It is possible of course, to empty too much gasoline vapor from the tube and reduce the air-vapor below the combustible range. With a little practice, however, you will have no difficulty in performing this demonstration.

Appendix B: Applicable Diagrams

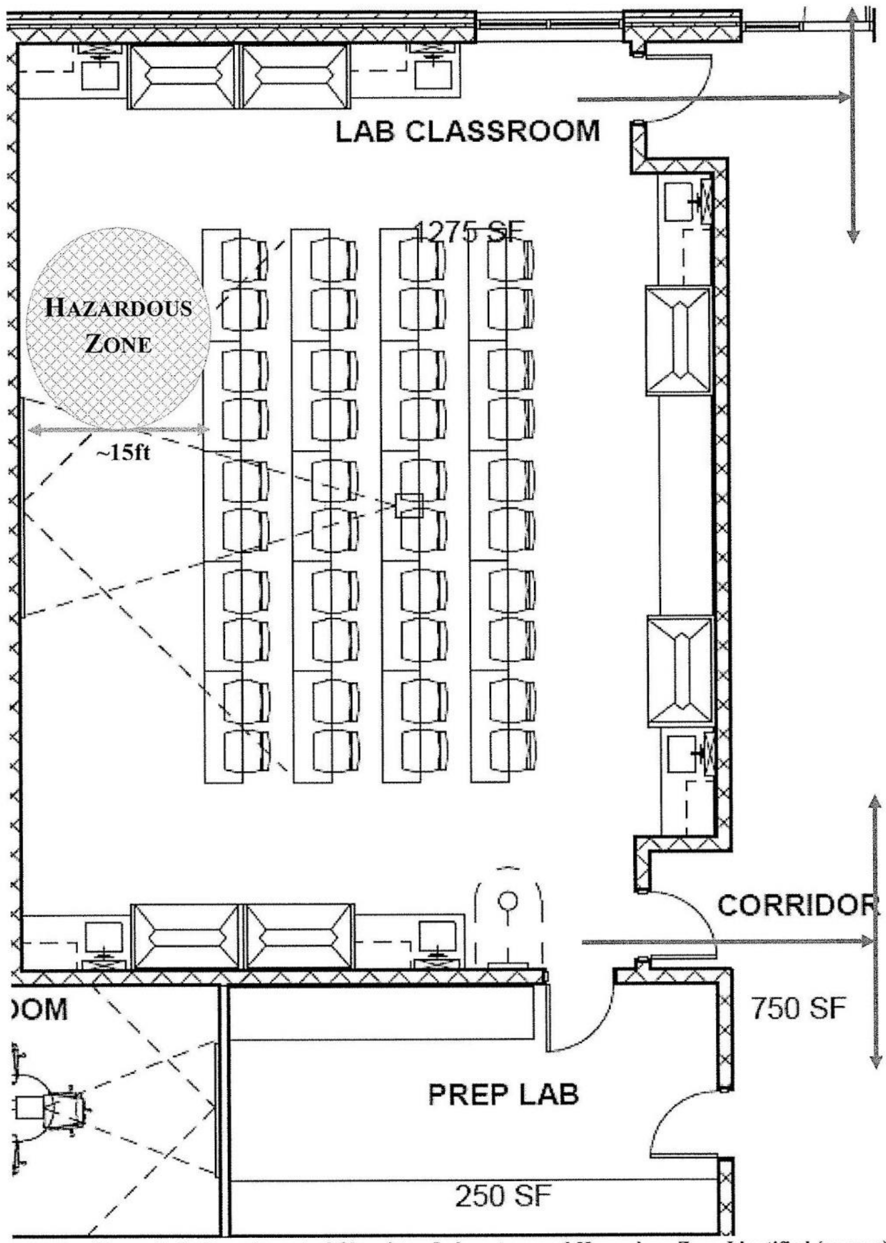


Figure 1: Exit routes out of Chemistry Laboratory and Hazardous Zone Identified (orange)

Appendix D: Applicable Hazardous Materials-Material Safety Data Sheets (SDS)

Safety Data Sheet

Material Name: Gasoline All Grades

SDS No. 9950
US GHS

Synonyms: Hess Conventional (Oxygenated and Non-oxygenated) Gasoline; Reformulated Gasoline (RFG); Reformulated Gasoline Blendstock for Oxygenate Blending (RBOB); Unleaded Motor or Automotive Gasoline

* * * Section 1 - Product and Company Identification * * *

Manufacturer Information

Hess Corporation
1 Hess Plaza
Woodbridge, NJ 07095-0961

Phone: 732-750-6000 Corporate EHS
Emergency # 800-424-9300 CHEMTREC
www.hess.com (Environment, Health, Safety Internet Website)

* * * Section 2 - Hazards Identification * * *

GHS Classification:

- Flammable Liquid - Category 2
- Skin Corrosion/Irritation - Category 2
- Germ Cell Mutagenicity - Category 1B
- Carcinogenicity - Category 1B
- Toxic to Reproduction - Category 1A
- Specific Target Organ Toxicity (Single Exposure) - Category 3 (respiratory irritation, narcosis)
- Specific Target Organ Toxicity (Repeat Exposure) - Category 1 (liver, kidneys, bladder, blood, bone marrow, nervous system)
- Aspiration Hazard - Category 1
- Hazardous to the Aquatic Environment – Acute Hazard - Category 3

GHS LABEL ELEMENTS

Symbol(s)

Signal Word

DANGER

Hazard Statements

- Highly flammable liquid and vapour.
- Causes skin irritation.
- May cause genetic defects.
- May cause cancer.
- May damage fertility or the unborn child.
- May cause respiratory irritation.
- May cause drowsiness or dizziness.
- Causes damage to organs (liver, kidneys, bladder, blood, bone marrow, nervous system) through prolonged or repeated exposure.
- May be fatal if swallowed and enters airways.
- Harmful to aquatic life.

The remaining 15 pages of the document consist of a gasoline MSDS.

Appendix F

Summaries of NFPA 45, 54, and 58

Chapter 4:

- 4.2.2 Instructional labs must be Class C or Class D.
- This is an instructional lab: 3.3.31. Check what this means in NFPA 101.

Table 9.1.1(a):

FLAMMABLE AND COMBUSTIBLE LIQUIDS 45–19

Table 9.1.1(a) Maximum Quantities of Flammable and Combustible Liquids in Laboratory Units Outside of Inside Liquid Storage Areas (Metric)

		Quantities in Use[a]		Quantities in Use and Storage[a]	
Laboratory Unit Fire Hazard Class	Flammable and Combustible Liquid Class[a]	Maximum Quantity[b] per 9.3 m^2 of Laboratory Unit[c] (L)	Maximum Quantity[b] per Laboratory Unit (L)	Maximum Quantity[b] per 9.3 m^2 of Laboratory Unit[c] (L)	Maximum Quantity[b] per Laboratory Unit (L)
A (high fire hazard)	I	38	1820	76	1820
	I, II, and IIIA	76	3028	150	6060
B[d] (moderate fire hazard)	I	20	1136	38	1820
	I, II, and IIIA	38	1515	76	3028
C[e] (low fire hazard)	I	7.5	570	15	1136
	I, II, and IIIA	15	757	30	1515
D[e] (minimal fire hazard)	I	4	284	7.5	570
	I, II, and IIIA	4	284	7.5	570

Note: For maximum container sizes, see Table 9.1.2.
[a]The maximum amount in use in open systems is limited to 10 percent of the quantities listed.
[b]See 4.2.2 for additional requirements for educational and instructional laboratories.
[c]The quantities per 9.3 m^2 do not imply the quantities must be within that 9.3 m^2 area; the quantities per 9.3 m^2 are for calculation purposes to determine the total quantity allowed per laboratory work area and the total amount overall in the laboratory unit.
[d]Reduce quantities by 50 percent for B laboratory units located above the 3rd floor.
[e]Reduce quantities by 25 percent for C and D laboratory units located on the 4th–6th floors of a building, and reduce quantities by 50 percent for C and D laboratory units located above the 6th floor.

Chapter 5:

- 5.1.3 Walls must be 1 Hour Fire Resistant
- 5.1.6 Doors should be ¾ Hour Resistant
- 5.1.7 Allows us to leave windows in the building
    - 5.1.7.1 Need to check fire rating of windows and have them in accordance with fire resistant rating stated in NFPA 101.
    - 5.1.7.2 Check NFPA 80 for fire window assemblies (Do we need them?)
- 5.4.4 We need emergency lighting in our laboratory
- 5.4.5 Install emergency lighting with section 7.9 of NFPA 101.
- 5.6.2 Lab work areas, fume hood interiors shall be considered as unclassified electrically in compliance with Article 500 of NFPA 70 unless stated in 9.5.5 and 11.3.2.2

Chapter 6:

- 6.1.1.1 Automatic sprinkler systems for class C must be in accordance with NFPA 13 for ordinary hazard Group 1 occupancy
- 6.1.2 If water will create a hazard a suitable non water automatic extinguishing system is an acceptable substitute for sprinklers
    - Follow NFPA 11,12,12A,15,17,17A,69,750,2001
- 6.3.1 Portable fire extinguishers must be installed
- 6.5.3.3 Everyone in lab must be trained annually on the emergency plan
- 6.6.2 Wear Lab coats

Chapter 7:

- 7.4.11 Air exhausted from chemicals fume hoods and special exhausted systems shall be discharged above the roof at a location, height, and velocity sufficient to prevent re-entry of chemicals and to prevent exposures to personnel.
- 7.5.10.1 Exhaust ducts from each laboratory unit shall be separately ducted to a point outside the building, to a mechanical room, or to a shaft
- 7.7.1 Fans shall be selected to meet requirements for fire, explosion, and corrosion.
- 7.7.3 Fans shall be located and arranged so as to afford ready access for repairs, cleaning, inspection, and maintenance.
- 7.8.1.2 Chemical fume hoods shall meet the requirements of UL 1805, *Standard For Safety Laboratory Hoods and Cabinets*, or other approved standards.
- 7.9.1 Chemical fume hoods shall be located in areas of minimum air turbulence.
- 7.9.2 chemical fume hoods shall not be located adjacent to a single means of access to an exit or to high-traffic areas
- 7.9.3 workstations not directly related to the chemical fume hood activity shall not be located directly in front of chemical fume hood openings
- 7.14.4.1 Air system flow detectors, if installed, shall be inspected and tested annually

Chapter 8:

- 8.2.2.3 Chemicals shall be stored and handled so as to limit spills to a max of 20 L or 5 gallons.
- 8.2.3.3 Need to determine safe disposal of hazardous materials and wastes prior to using a given chemical
- 8.2.4.2 Incompatible liquids shall be separated to prevent accidental contact
- 8.2.4.3 Class 1 flammable and Class II combustible liquids not in use shall be stored in safety cans and in approved storage cabinets - NFPA 30 or ANSI/UL 1275
- 8.2.4.4 Date time sensitive liquids - define time sensitive materials and when to and how to check them
- 8.3.3 label chemical waste containers

Chapter 9:

- 9.1 density and total amount of flammable and combustible liquids (including waste) in work areas and in the laboratory unit outside of the flammable liquid storage rooms can not exceed
- 9.1.2 Containers for Class I and Class II liquids shall not exceed safety cans 8L or other containers of 4L

  Class IA - Flash Point less than 73°F; Boiling Point less than 100°F
  Class IB - Flash Point less than 73°F; Boiling Point equal to or greater than 100°F
  Class IC - Flash Point equal to or greater than 73°F, but less than 100°F
  Class II - Flash Point equal to or greater than 100°F, but less than 140°F
  Class IIIA - Flash Point equal to or greater than 140°F, but less than 200°F
  Class IIIB - Flash Point equal to or greater than 200°F
- 9.2 Supply piping for flammable/combustible liquids must comply with NFPA 30
- 9.3.1 Dispensing Class I liquids to or from containers less than or equal to 20L shall be performed in a fume hood or area with proper ventilation
- 9.3.3 Class I liquids shall not be transferred between conductive containers
- 9.4.2 Nonmetallic containers larger than 4L shall not be used
- 9.5.1 Storage cabinets used for flammable and combustible liquids shall be constructed in accordance with NFPA 30
- 9.5.4 Baths containing flammable/combustible liquids heated to their flash points must be placed in a fume hood

Chapter 10:

- 10.1.1 Only teachers are allowed to handle the containers with gases in them.
- 10.1.2 Cylinders that are not 0.5 kg (1 lb) propane containers for recreational use must be stored outside the classroom in accordance with NFPA 55.
- 10.1.4 We should not need this section as long as we have gases and stuff that is a health hazard rating of a 3 or rated as safe by NFPA 704 (don't need to actually reference this NFPA, as long as it is rated as a safe chemical)
- 10.1.5.1 Cylinders shall be placed in holders.
- 10.1.5.2 Cylinders shall be marked with a pressure gauge (like they are in Goddard)
- 10.1.6.4 Cylinders not in use shall not be stored in the laboratory.
- 10.1.6.5 Cylinders shall be in accordance with Table 6.3.1 in NFPA 55.
- 10.1.6.8 Quantity of compressed and liquified gases shall be 10 percent of what is stated in Table 6.3.1 in NFPA 55.
- 10.2.1 Storage and pipelines of gas shall be in accordance with NFPA 51, 54, 55, and 58.
- 10.2.3 Each gas connection shall have a manual shut off valve.
- 10.2.3.4 There should be an emergency shutoff valve at the front of the room (near the double doors) that can be used to shut off all gas in the room.

Chapter 11:

- 11.2.1.1 before laboratory test or chemical reactions have begun evaluations of potential hazards must be made

- 11.2.1.3 regular reviews of laboratory operations and procedures shall be conducted with special attention given to any changes in materials, operations, or personel
- 11.2.2.1 All heating of flammable/combustible liquids shall be conducted so as to minimize fire hazards
- 11.2.7.1 when possible, use alternatives to open flames eg hot plates. Open flames outside of a hood shall not have anything hanging over them.
- 11.3.3.1 All electrical heating equipment that are left unattended should have a temperature of time automatic shut off valve attached to it.

Chapter 12:

- 12.2 Instructors must conduct demonstrations safely (more detail in code). Instructors shall be trained in fire safety procedures and emergency plans.
- 12.3.1.3 Dispense bulk quantities of chemicals prior to students' arrival.
- 12.3.2: Perform flammable or toxic experiments in a location that does not block access to means of egress. Perform experiments that produce hazardous quantities of vapors in a fume hood. Experiments outside a fume should be 10 ft from students or have a shield around them.

Chapter 13:

- 13.2.1: label entrances of labs with signs warning of unusual or severe fire hazards. Also label exhaust systems.
- 13.2.2 these hazards shall be communicated in firefighting plans
- 13.5 Graphic systems used to identify hazards shall comply with ANSI Z535.1, .2, .3, and .4 or other approved systems.

Appendix G

List of Equipment and Costs from Diprolab

Equipment	CRC per item	Possible Quantity	CRC Total	USD Total	Provider	Description
Benches	944000	4	3776000	6800	Fisher Scientific	Lab table. Alternately, build with local carpenter
Sink	294000	4	1176000	2116	Fisher Scientific	Drop-in epoxy sink. Alternately, from local suppliers/builders
Stools	14000	25	350000	625	Wal-mart	SImple wooden stool. Alternately, build with local carpenter
Balance	117000	2	234000	421.2	Diprolab	Local
Graduated cylinder 25mL	5700	8	45600	82.08	Diprolab	Local
Graduated Cylinder 50mL	6005	8	48040	86.472	Diprolab	Local
Graduated Cylinder 100mL	8270	8	66160	119.088	Diprolab	Local
Beaker 50mL	1190	8	9520	17.136	Diprolab	Local
Beaker 100mL	2060	8	16480	29.664	Diprolab	Local
Beaker 600mL	2900	4	11600	20.88	Diprolab	Local
Lab Coats	12000	25	300000	540	Diprolab	Local
Safety Glasses	1770	25	44250	79.65	Diprolab	Local
Hot Plate and Stirrers	348100	2	696200	1253.16	Diprolab	Local
Thermometer	3240	4	12960	23.328	Diprolab	Local
Eye wash and safety shower	300000	1	300000	540	Amazon, Haws, Hughes, EyewashDirect, etc.	
Bunsen Burner	15000	8	120000	216	Diprolab	Local
Total			*1904810*	*$3,428.66*		

Recurring Purchases	CRC per item	Possible Quantity	CRC Total	USD Total	Provider	Description
Gloves (Any Size)	4000	3	12000	21.6	Diprolab	Per Box
Pipettes, 3mL	12000	1	12000	21.6	Diprolab	For 500
Test Tubes, 100mm	195	5	195	0.351	Diprolab	For 16
Total			*24000*	*$43.20*		

Future Purchases	CRC per item	Possible Quantity	CRC Total	USD Total	Provider	Description
Cone Calorimeter	14000000	1	14000000	25,000	Fisher Scientific	International
Fire-proof Storage Cabinet	720000	1	720000	1300	Fisher Scientific	International
Fume Hood	6000000	1	6000000	10800	Fisher Scientific	International
Water Distiller	666000	1	666000	1200	Thomas Scientific	International
Open Cup Tester	672000	1	672000	1210	Gilson Company	International
Fire-resistent Lab Coat	109850	*1*	109850	195	Fisher Scientific	International
Fire-resistent Gloves	*14660*	*1*	14660	26	Galeton	International
Total			*22182510*	*$39,731*		

Diprolab de Centro América Corp. S.A
SAN JOSE
MONTES DE OCA
22348242

Fecha: 29/01/2020

Fecha Prometida: 29/01/2020

Cotización: PED-0000014126

Cliente: C-00000024 CLIENTE CONTADO

Telefono: 99999999
País: CRI Costa Rica
Vendedor: ND NO DEFINIDO
Condición de Pago: 0 CONTADO
Moneda de Cotización: Local
Atención:

Código	Descripción	Un.	Precio	Pedida	Monto Desc.	Total
BOE5010617	Beaker vidrio 50mL, boro 3.3, (Boeco/Pyrex)	UNID	1,190.00	1.00	0.00	1,190.00
BOE5010624	Beaker vidrio 100mL, boro 3.3, Boeco	UNID	2,060.00	1.00	0.00	2,060.00
BOE5010648	Beaker vidrio 600mL, boro 3.3, Boeco	UNID	2,900.00	1.00	0.00	2,900.00
BOE5010654	Beaker vidrio 1000mL, boro 3.3, Boeco	UNID	4,920.00	1.00	0.00	4,920.00
308	Probeta vidrio 25mL, graduacion azul, clase A, LMS	UNID	5,700.00	1.00	0.00	5,700.00
307	Probeta vidrio 50mL, graduacion azul, clase A, LMS	UNID	6,005.00	1.00	0.00	6,005.00
306	Probeta vidrio 100mL, graduacion azul, clase A, LMS	UNID	8,270.00	1.00	0.00	8,270.00
305	Probeta vidrio 250mL, graduacion azul, clase A, LMS	UNID	9,650.00	1.00	0.00	9,650.00
BLC 1500	Balanza electrónica 1500g/0.1g	Unid	117,000.00	1.00	0.00	117,000.00
801	Lentes seguridad antiempañantes	Unid	1,770.00	1.00	0.00	1,770.00
1530	Guante Nitrilo L	UNID	4,000.00	1.00	0.00	4,000.00
2167	Gabacha Lineta Talla L	Unid	12,000.00	1.00	0.00	12,000.00
200	Mechero bunsen Premiere	Unid	15,000.00	1.00	0.00	15,000.00
255	Pipeta Pasteur Descartable 3ML 500 UNID	Unid	12,000.00	1.00	0.00	12,000.00
0152	Bureta vidrio 50/0.1mL BOE 5256725	UND	27,100.00	1.00	0.00	27,100.00
302	Termometro alcohol rojo -10+110°C	Unid	3,240.00	1.00	0.00	3,240.00
0033	Agitador y Calentador MS7-H550-S, USA plug, 110V/60HZ, Cod.8130122211, marca DLAB	Unid	348,100.00	1.00	0.00	348,100.00
361	Tubo ensayo 16x100mm	Unid	195.00	1.00	0.00	195.00

Total Mercadería:		581,100.00
Descuento 1:	0.00 %	0.00
Impuesto	Venta	75,543.00

Appendix H

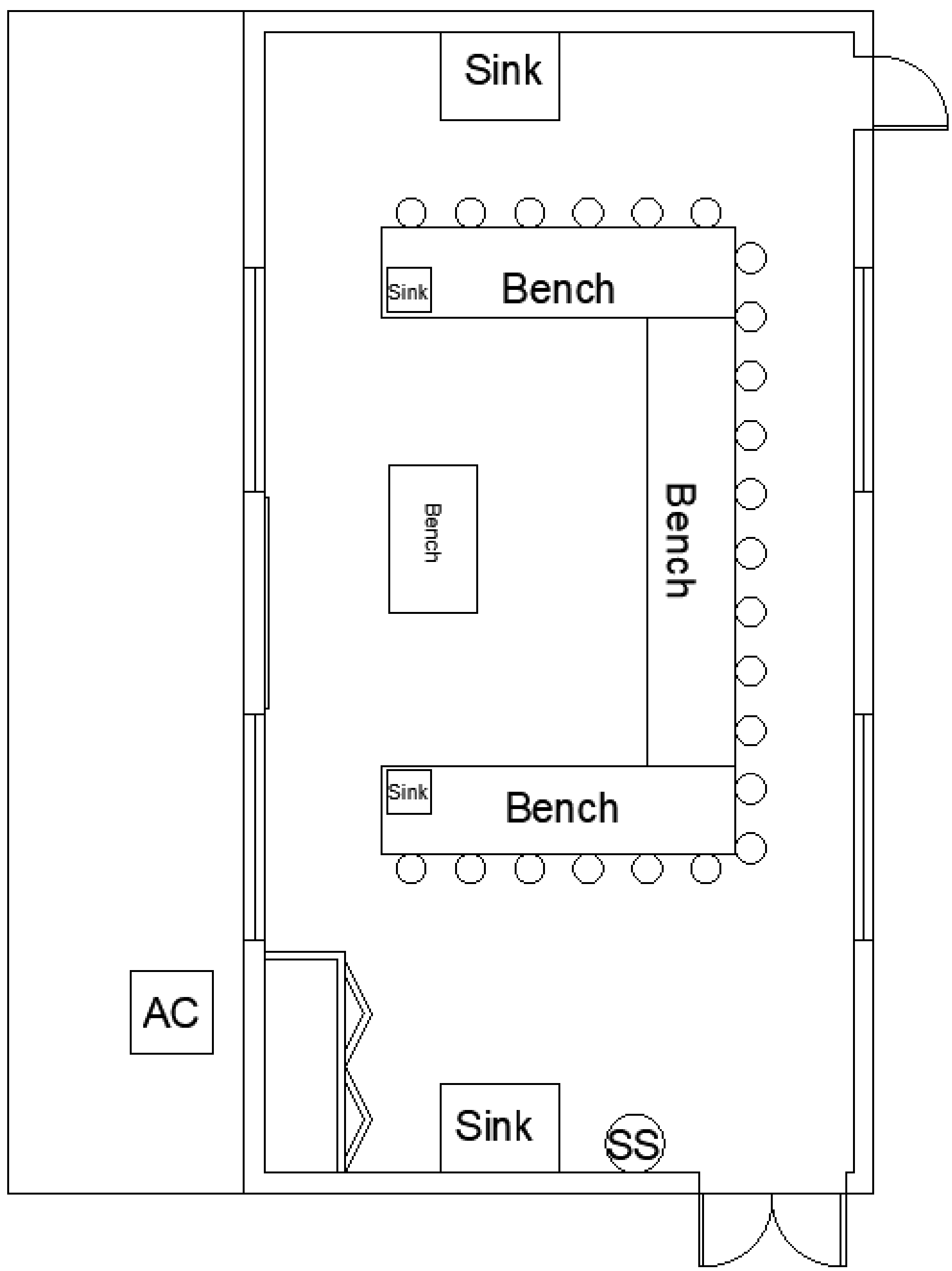
List of Chemicals and Prices

Chemical	Fisher Scientific	CRC per qty	Catolog No.	Quantity
Acetone	$110.00	62998	A18-1	1L
Nitric Acid	$57.10	32702	AC133620010	1L
Sulfuric Acid	$98.00	56125	SA213	100mL
DI Water	$57.40	32873	9180-32	1L
Ethanol	$114.10	65346	AC615090010	1L
Phenolphthalein (Indicators)	$25.85	14804	50-440-0275	.1l
Gasoline	$44.60	25542	06-728-505	1mL
HCl	$88.00	50398	A142-212	2.5L
Hexane	$39.65	22708	AA42100K2	1L
KHP	$49.08	28108	NC0621054	1L
KI	$195.00	111678	AC418265000	500g
KIO3	$40.25	23051	ICN217545	100g
KMnO4	$51.12	29277	60-012-94	1L
KOH	$41.90	23997	6198-16	500mL
NaCl	$78.75	45100	18-606-428	500g
NaOH	$47.25	27060	AC259860010	1L
Toluene	$57.30	32816	AC326980010	1L
Iodine	$98.00	56125	SI86-1	1L
Total	*$1,293.35*	*740708*		

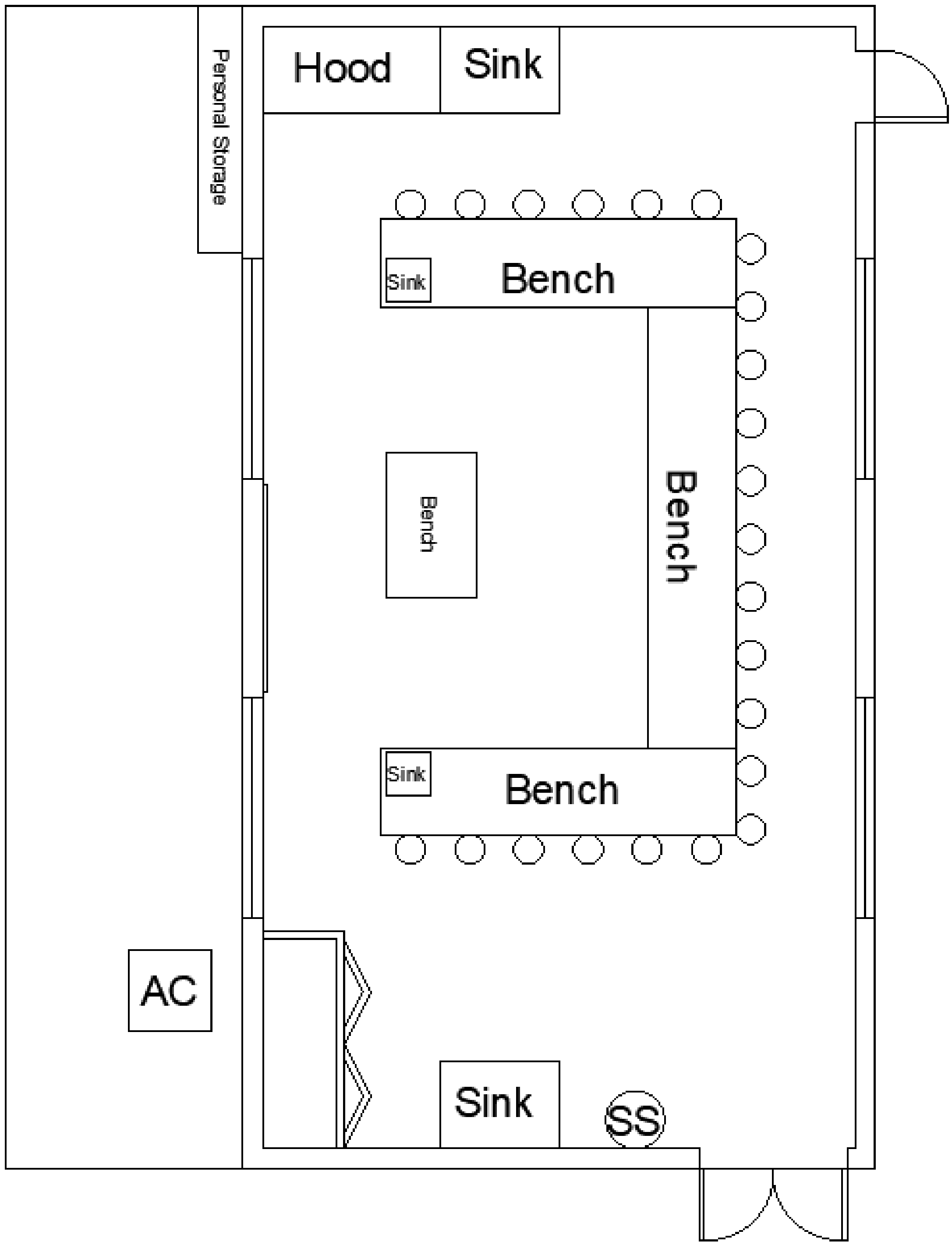
Appendix I

Five Year Plan Designs

Year 1

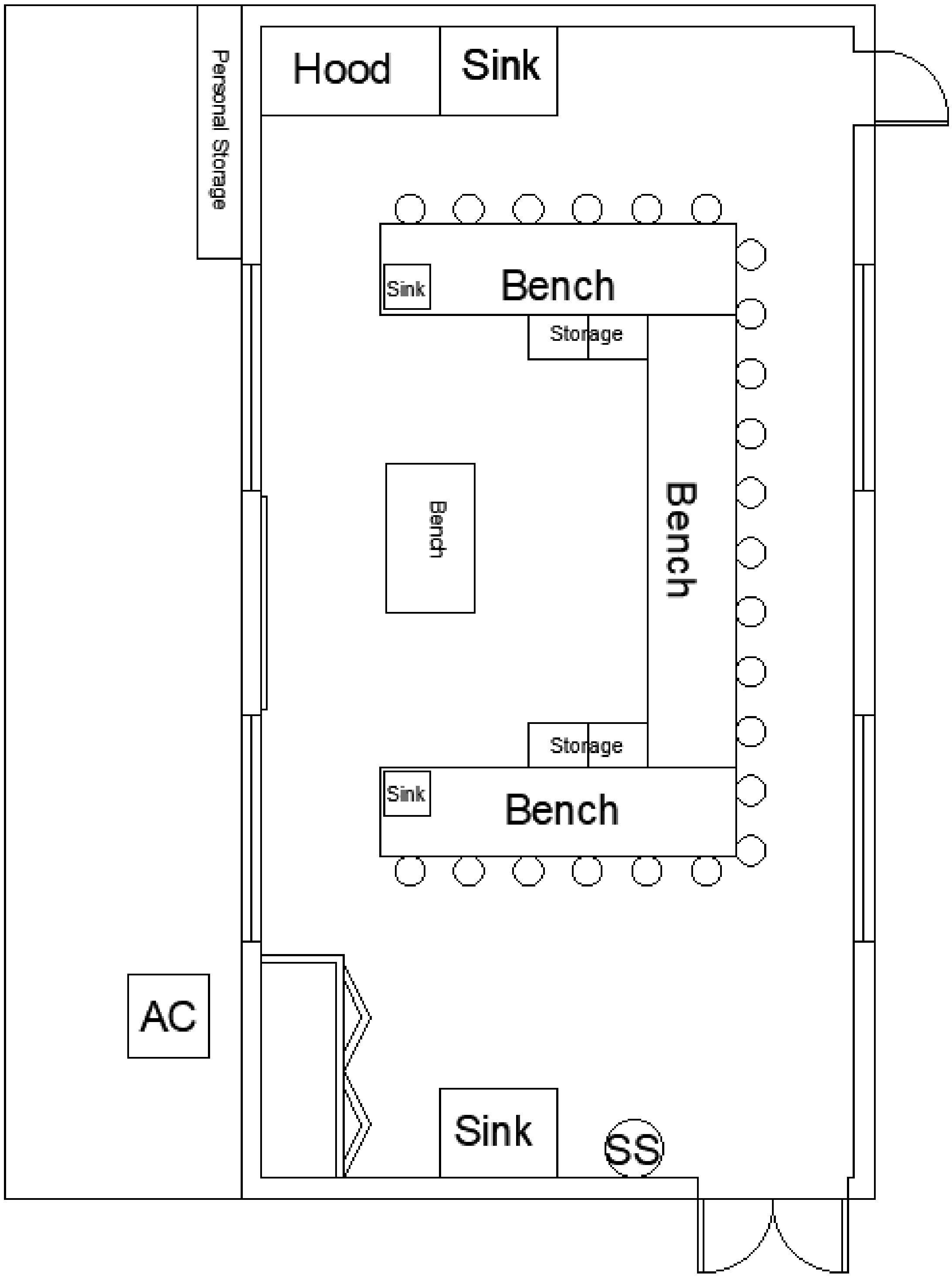


Year 2



Personal Storage
Hood
Sink
Sink
Bench
Bench
Bench
Sink
Bench
AC
Sink
SS

Year 3



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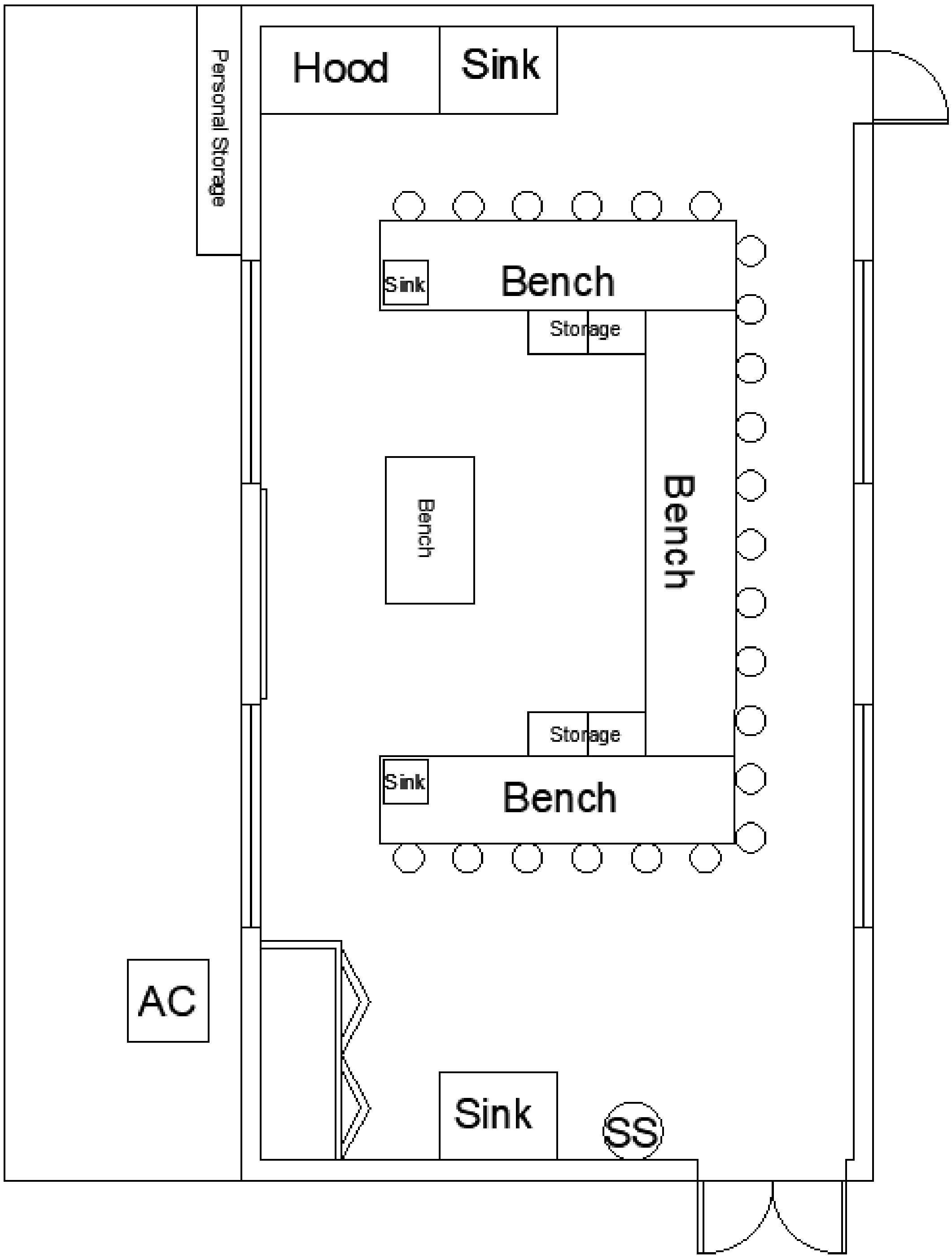
Year 4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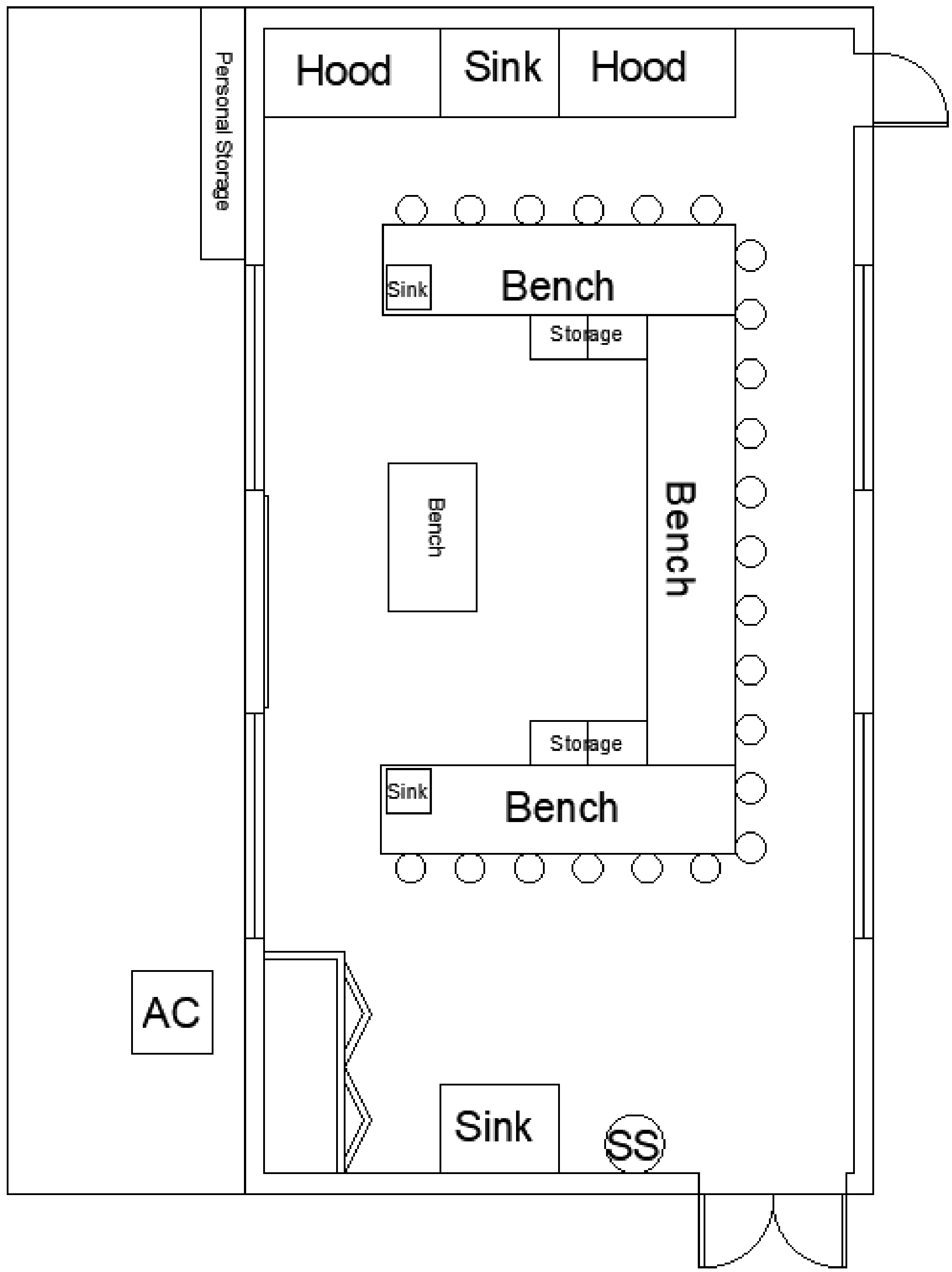
Year 5



Personal Storage
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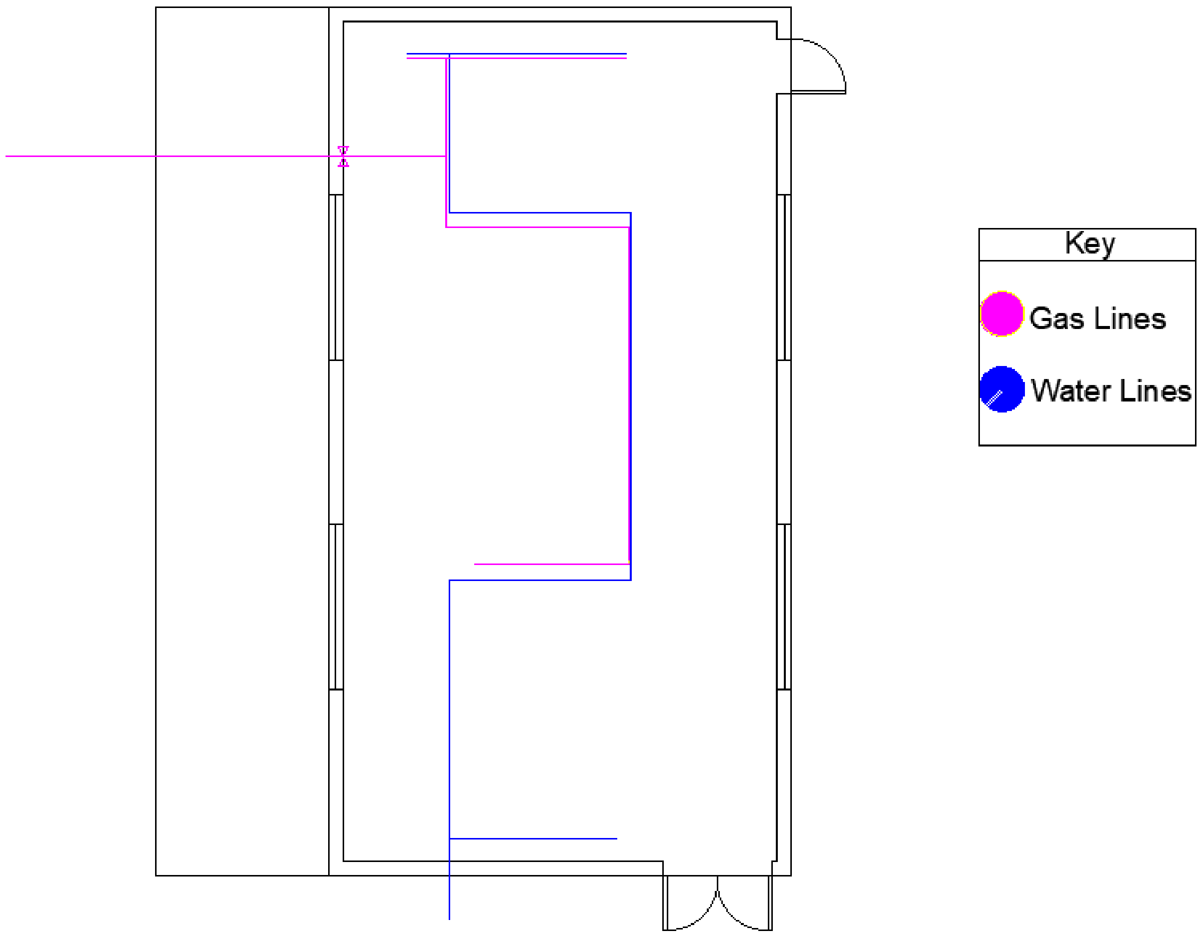
Appendix J

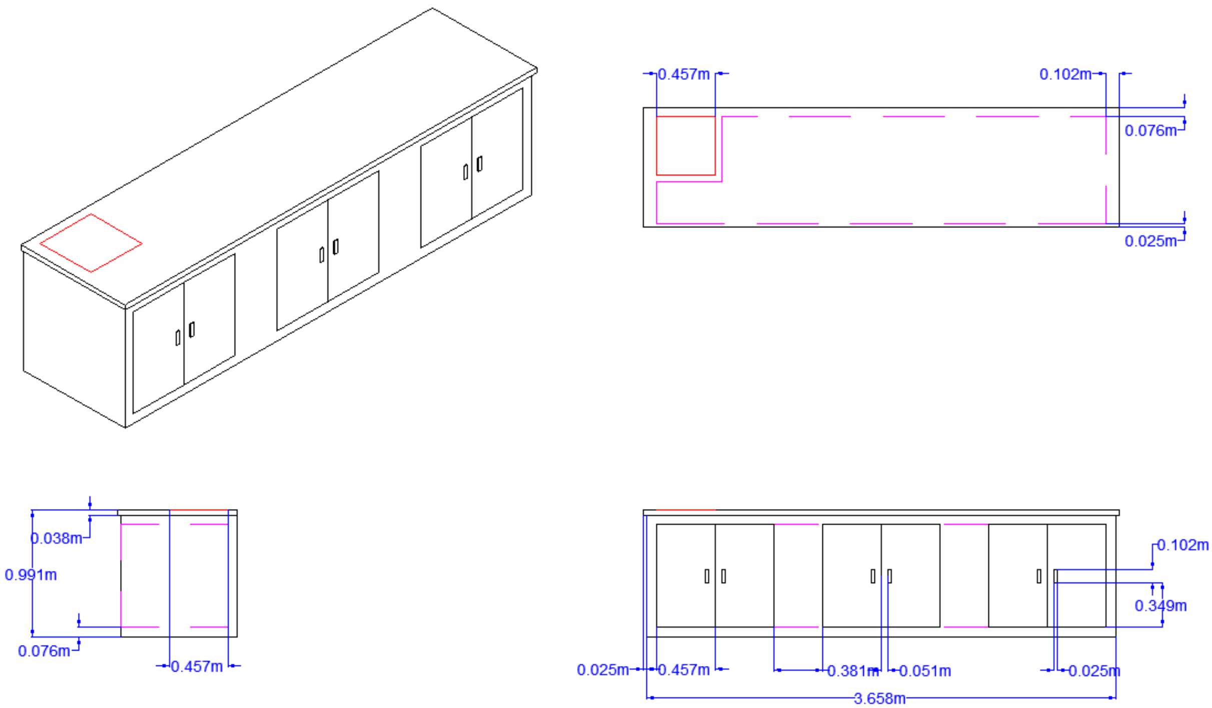
Water and Gas Line Design



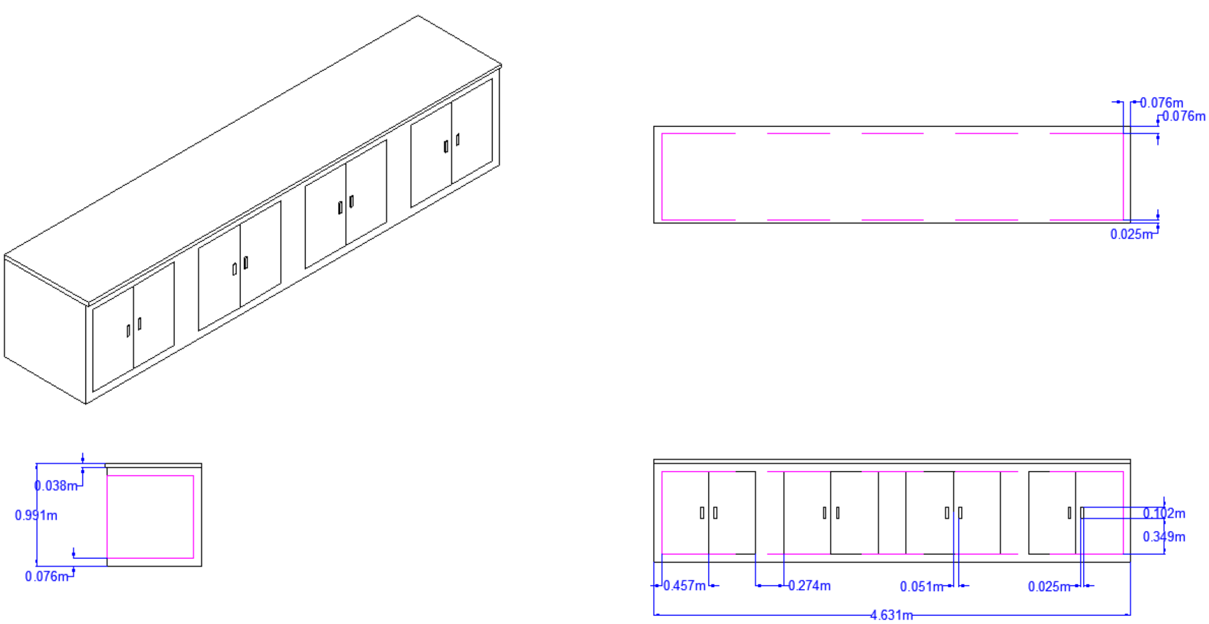
Appendix K

Lab Bench Designs

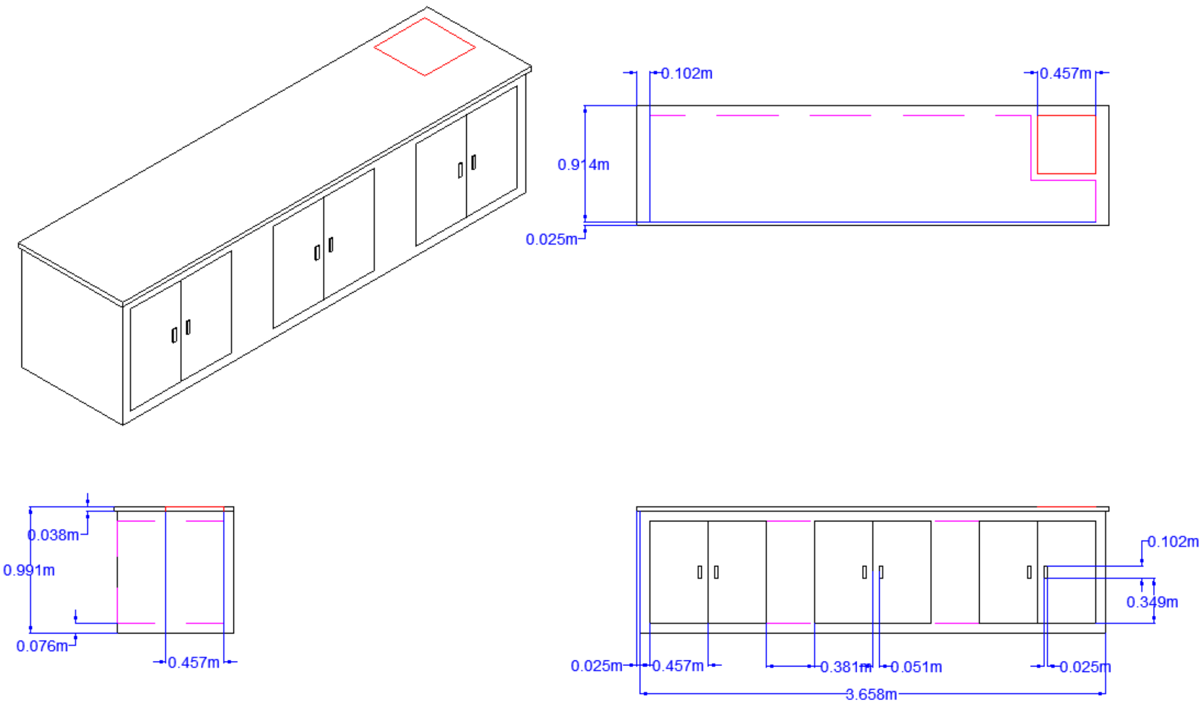
Bench 1 Design



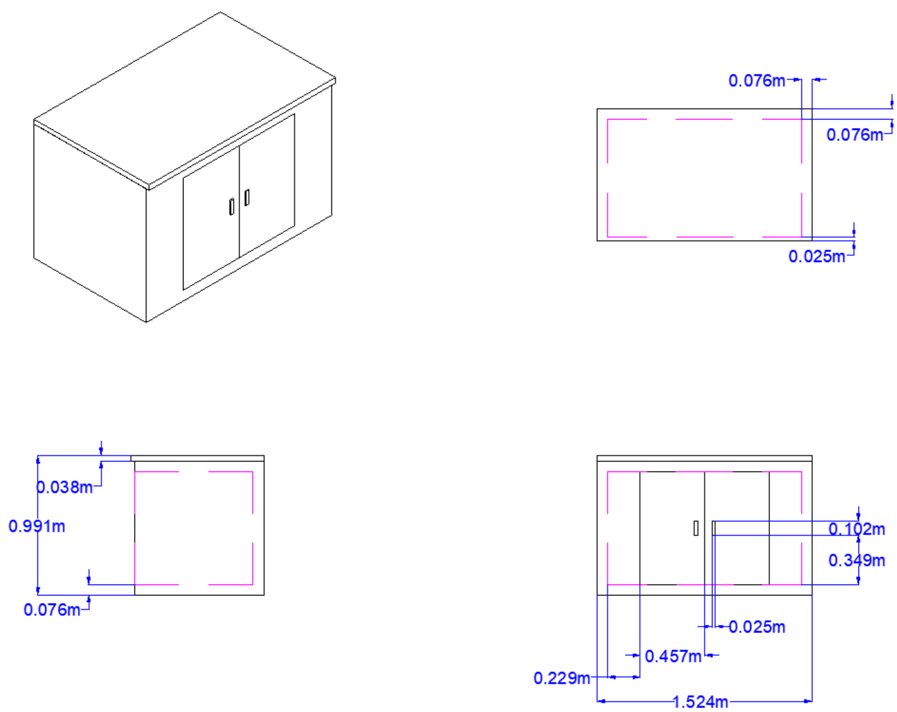
Bench 2 Design



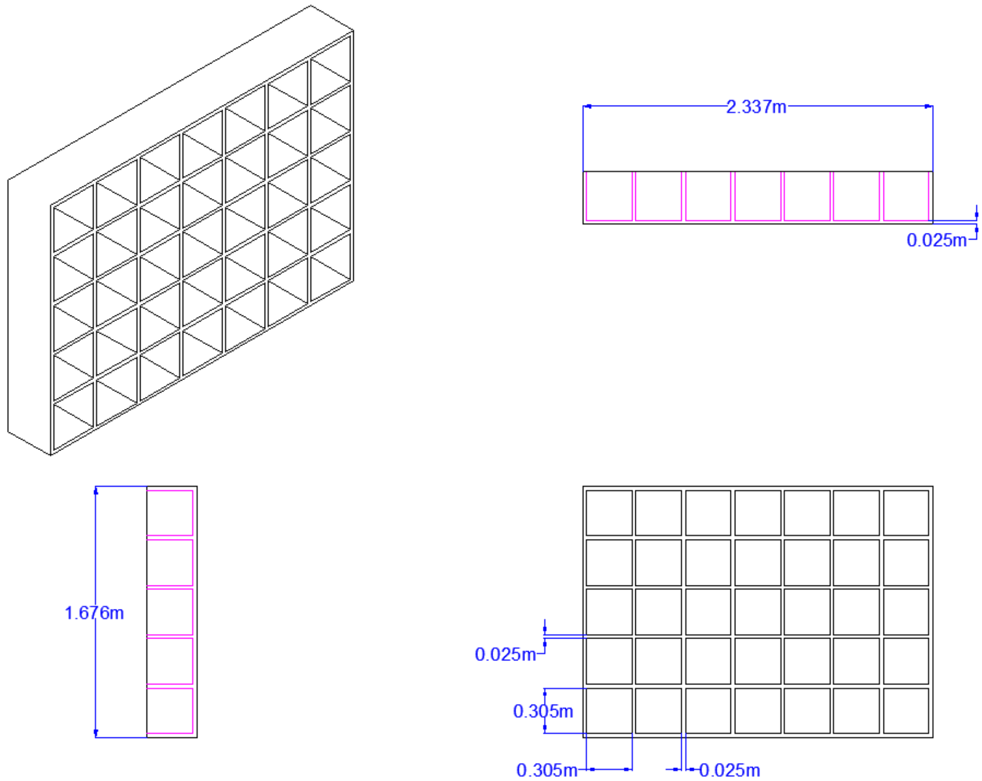
Bench 3 Design



Teachers Bench Design



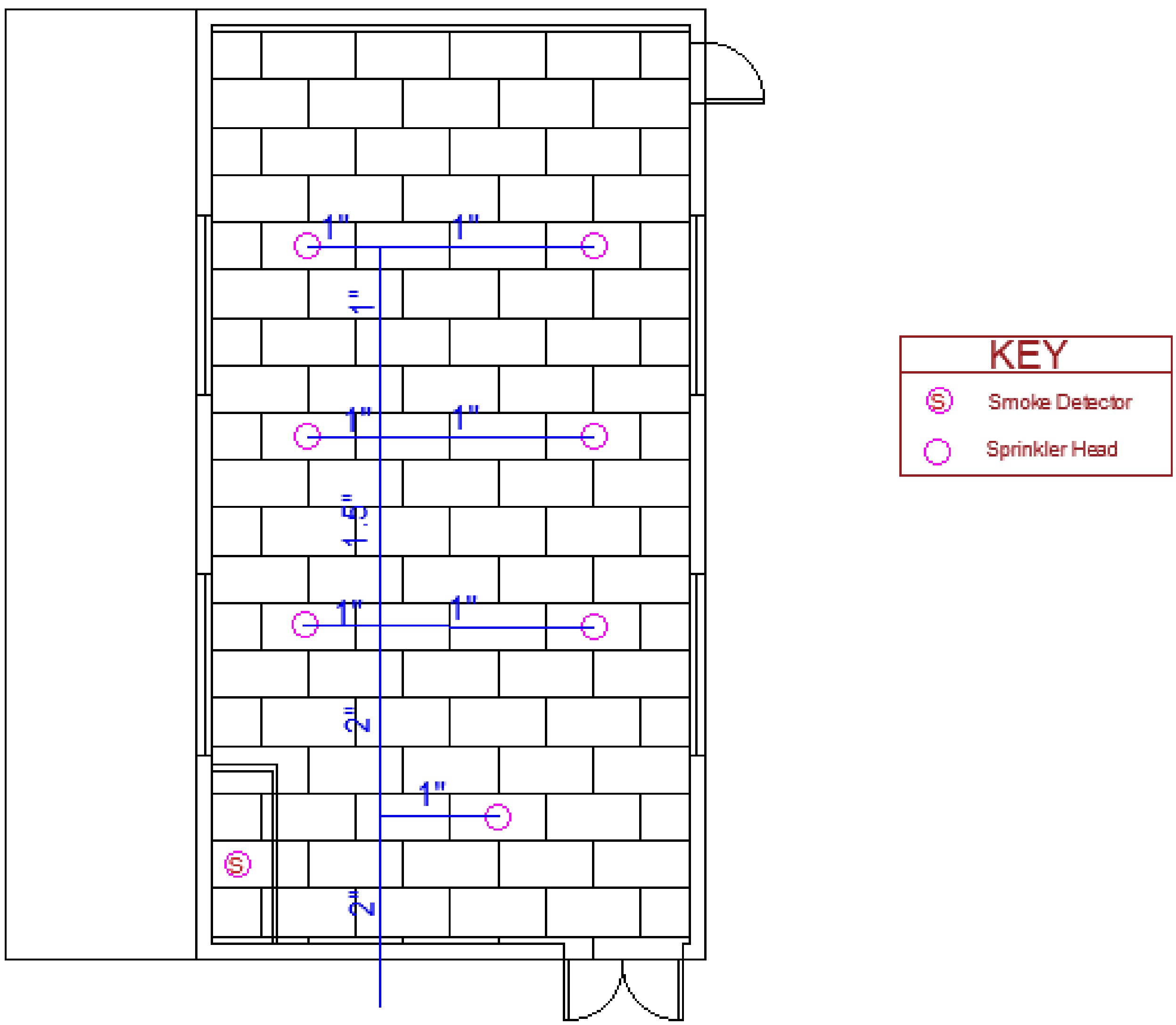
Personal Storage Units Design



Appendix L

Fire Protection and Life Safety Plans

Sprinkler Plan



Life Safety Plans