STEM Innovation and Modernization of the Chemistry Service Laboratories for Undergraduate Education

Over the past two years the focus of energy and innovation within the chemistry department has been on the STEM Modernization of the Upper Level Chemistry Laboratories taken predominantly by our majors. Those labs were dreadfully under equipped and the supporting instrumentation either old or non-functional. After two rounds of grants and some very successful bargaining, the labs are much better equipped and new laboratory experiments are being implemented. At this point the department now needs to turn its attention to those courses (CHM1045L, CHM1046L, CHM2211L predominantly) that act as service courses for many of the STEM majors across campus. While the instrumentation used in these courses is not nearly as expensive individually, enrollment numbers make the purchase of new equipment cost prohibitive within the normal fee allotments. What follows in this proposal is a description of the innovative curricula that the labs would like to implement and the equipment required to both maintain current standards as well as develop these new laboratory experiments.

Overview/Goals

We request funds to substantially upgrade and expand the laboratory equipment and associated technology infrastructure used in the two workhorse undergraduate laboratories serving over 4,200 students each year from a variety of majors across campus. The primary motivation of this upgrade and innovation request is to implement newer technologies and improve the job-readiness of our students while modernizing the STEM curriculum that Chemistry and Biochemistry Department provides.

Background

While the equipment and technology deficiencies on the 3rd floor of HTL are not as severe as those on the 4th or 5th floors of HTL, in their current condition, these facilities are such that instructional goals are becoming more and more difficult to achieve. Thus, this proposal will focus on the General and Organic Chemistry laboratory needs in terms of equipment and instrumentation as these classes handle in excess of 4,200 students each year.

The concepts taught in these labs <u>are</u> current. However, the equipment used to illustrate the concepts is either woefully outdated or simply worn out. Complementary to the equipment and instrumentation issues are the needs for computer and video systems that interface with them.

In this proposal we also outline an effort to introduce video capabilities into the Organic Chemistry labs on the 5^{th} floor of HTL. Just as Dr. Dillon did with the allocation she received from this Committee in 2014, Dr. Profeta hopes to duplicate the configuration of projectors in each lab, and to also add *interactive* screens to facilitate student participation during the videos. Video instruction will be developed to review concepts from each lab and the 'mechanics' of experimental apparatus and procedures. The video system will be used to train students in the use of new equipment such as the Infrared (IR), UV-Visible and Mass Spectrometry devices that are being requested in this proposal.

In the following, we outline our request that is divided into two distinct parts. The first part describes the equipment requested for each course. The second part outlines new video equipment that is requested for the Organic Chemistry labs and the necessary upgrades to our computing/communications infrastructure.

<u>The Department is playing catch-up in funding its instructional infrastructure relative to a number of Florida and regional schools; correcting this situation carries with it a significant but unavoidable price tag.</u> The total request, while quite substantial, represents an investment of just $259 per student **for a single year**. The projected lifetime of the instrumentation, particularly, spans between 5 and 10 years considering both the rate of change of the technology and the wear and tear of serving 4,200+ students in General and Organic Chemistry per year. If we use a 5-year amortization, the cost per student is reduced to $52.

Surely, a pre-eminent University that strives to be in the 'Top 25' should be willing to make such an investment in its STEM-intensive instructional infrastructure, particularly in light of the decades of neglect that have plagued the facilities and curriculum in the past. This revitalization needs to begin now or in the very near future as with each passing semester we are further undermining our ability to stay relevant in the hands-on training we are giving our students.

CHM1045L, CHM1046L, CHM1050L and CHM1051L

The General Chemistry I Laboratory is offered year round with a total of 96 sections of 24 seats or 2304 students annually. Additionally an honors version of the General Chemistry I Laboratory (CHM1050L) is offered each fall with a typical enrollment of ~120 students. Each of these labs runs 12 experiments each semester, 10 of which are what is referred to as “wet labs” meaning actual chemically based, hands-on experimental protocols are used. The other two experiments are computer based exercises. The General Chemistry II Laboratory is offered year round with a total of 56 sections of 27 seats or 1512 students annually. Each of these labs also runs 12 experiments each semester, 10 of which as “wet labs”. The honors II lab was recently revised to be more research based and is an area in which innovation is most needed with respect to the equipment choices provided to the students. The equipment currently used in the labs includes analytical balances, pH meters, centrifuges, hotplates, voltmeters, and spectrometers. Because of heavy use, the loss of equipment is a week to week occurrence.

A majority of the general chemistry requests are based on the upgrade of older equipment or the need to purchase more equipment based on the current enrollments. In an ideal situation, each student would have their own instrument to work on for each of the experiments we perform. Currently due to the numbers of instruments, specifically pH meters and spectrometers, students are forced to work in groups. One of Dr. Dillon’s goals is to both update the instrumentation being used as well as provide enough equipment such that each student can perform the experiments independently.

pH meters are currently used in 5 laboratory experiments (2 CHM1045L and 3 CHM1046L) as well as several experiments in the honors labs. The pH meters on hand number less than 40 and are approximately 10 years old. On days when both the CHM1045L/50L and CHM1046L/51L courses are using the meters this means that there is only 1 pH meter for every ~6 students or at best 1 meter per bench top AND we lose 1 or 2 meters every time we run a lab at this point due to age or simple student abuse. One of the main requests we will make in this proposal is enough pH meters to accommodate the number of students in the labs. The number of working spectrometers on the 3rd floor has been consistently declining over the past years so that a replenishing is now urgent.

In addition to the purchase of more of the most robust models of the pH meters and spectrometers to compensate for both age and loss we are additionally requesting a limited number of higher precision instruments for use in the honors sections of the labs. As was referenced previously the honors general chemistry II lab recently underwent a complete revision to a research based lab model where students are expected to design and perform 6 unique laboratory projects. Several of the laboratories require much more precise instrumentation or instruments currently unavailable in the general chemistry laboratories to be conducted properly. Most urgently needed are spectrometers capable of a far greater range (190nm-1100nm) for investigation. Along this same line is the need for higher precision analytical balances. The labs currently use a 1 mg model as it is very durable but the work being completed in the honors courses often requires a higher precision (0.1mg). If funded, the increase in both quantity and quality of instrumentation will allow further revision of the CHM1050 course and the addition of several new laboratory experiments in general chemistry I specifically introducing the topics of spectroscopy and titration at a much earlier point in the educational process which in turn will allow for higher level investigations in the Chemistry II lab. As both labs serve as the foundation courses for all of the higher level labs that follow, the sooner the students are introduced to these techniques the better as it allows Dr. Dillon to present several experiments using each technique. The repetitive exposure and variation of usage the students are taught makes them much better prepared for the higher level labs as well as the future job market.

For modernization, we request the following:

- **<u>100 pH Meters</u>**
  Sartorius pH meters for use in the CHM1045L and CHM1046L Labs
  Price: $925.00 **Total: $92,500.00**

- **<u>20 Spectrometers</u>**
  Spectrometer Genesis 30 for use in the CHM1045L and CHM1046L Labs

Price: $2,475.00 **Total: $49,500.00**

For Innovation, we request the following:

- **<u>18 Analytical Balances</u>**
  Mettler Toledo Analytical Balances for use in the CHM1050L and CHM1051L Labs
  Price: $1169.00 **Total: $21,042.00**

- **<u>2 UV-VIS Spectrometers</u>**
  Cary 60 UV-Vis for use in the CHM1050L and CHM1051L Labs (includes software, computer and installation)
  Price: $8000.00 **Total: $16,000.00**

The grand total for updating and improving the CHM1045L, CHM1050L, CHM1046L and CHM1051L courses is ~ **$179,042.00**

CHM2211L, CHM2200L (and CHM4610L)

CHM2211L (Organic Chemistry II lab) is the Organic Laboratory for Chemistry & Biochemistry and Chemical Science Majors. In this one-semester course students perform 20+ experiments that cover exemplary techniques illustrating subject matter covered in the Organic Chemistry I and II lecture courses. *<u>This is an instructionally intensive course that is very resource demanding</u>*. [As far as we are aware, it is the only 3 semester-hour version of Organic Chemistry laboratory (either as a single semester or two) within the SUS. It has been modelled after UC Berkeley's analogous course.] Although this is a Chem & Biochem major's course, it also serves a great number of students from other majors, including multiple Human Sciences majors, biology, psychology, and engineering. Annually, 40 sections of 16 students are offered (672 students); it is the most heavily subscribed of the Upper-Level labs impacted by any of the Technology Fee Allocation requests in recent years.

Starting in the Spring 2017 semester, we have dedicated two sections of CHM2211L for Honors students only. We are working with the new Honors Program Director, Dr. Mark Kearley, [who taught CHM2211L prior to Dr. Profeta's arrival] to make the course even more relevant and challenging for these talented and highly motivated students [who have a wide variety of professional interests].

CHM2200L (Survey Organic Chemistry lab) is the Organic Laboratory course for some Human Science Majors and any Liberal Arts major requiring a one-semester laboratory course. This lab is routinely taken with or after the CHM2200 Survey Organic Chemistry lecture (the pre- or co-requisite). Enrollment in this course includes 12 sections of 16 students (192 students) many of which are Human Science majors. While this course is not nearly as demanding in terms of curriculum and resources, it still requires technology infrastructure upgrades as well as being a lab that is 'ripe' for innovation. Fortunately, CHM2200L's infrastructure piggybacks directly on the resources that are available for CHM2211L. This facilitates a long-term innovation strategy for CHM2200L that is only limited by the speed with which the new resources are introduced into CHM2211L.

The CHM4610L course is the Advanced Inorganic lab for our majors and ChemE students whose enrollment is typically 3 sections of 14 (42 students) annually (Spring & Summer semesters). This lab focuses on the synthesis and characterization of inorganic and organometallic compounds/materials and uses much of the same equipment as CHM2211L. For this reason, and as is the situation for CHM2200L, we have folded CHM4610L's needs with CHM2211L into a single category.

As with the Upper-Level Analytical and Physical Chemistry courses whose technology we have dramatically improved in the past two years [thanks to the generous allocations from this Committee], the Organic and Inorganic labs depend heavily on the Department's Computer Laboratory for the analysis and computational processing of the data collected. Dr. Profeta, whose background includes 20 years of experience in the Pharmaceutical & Chemical industries, has been working diligently over the past several years to modernize and incorporate more industry preparatory experiments [involving both wet lab work and computational components] into the curriculum so that the department stays at the forefront of STEM education for both our majors and the other science majors in the STEM domains. The extent to which we are able to do so, however, is limited significantly by the technology and instrumental infrastructure that is available in the teaching laboratories. The purchase of the proposed instruments and technologies would permit the development of more experimental and computational procedures that are relevant to (STEM) jobs in the environmental, forensic and toxicological sciences, as well as the chemical, biochemical, petroleum, pharmaceutical and materials science industries.

Modernization and Innovation Upgrades

<u>Upgrading existing equipment and adding additional capacity: Infrared (IR) and Ultraviolet (UV) Spectrometers</u>

To keep our training current, articles in trade publications such as <u>*Chemical and Engineering News*</u> provide guidance for the curriculum needed in these labs. The table below outlined the various techniques an analytical chemist is expected to know for the pharmaceutical industry. Please note the correlation between the "Typical Analytical Techniques" and the requested equipment upgrades.

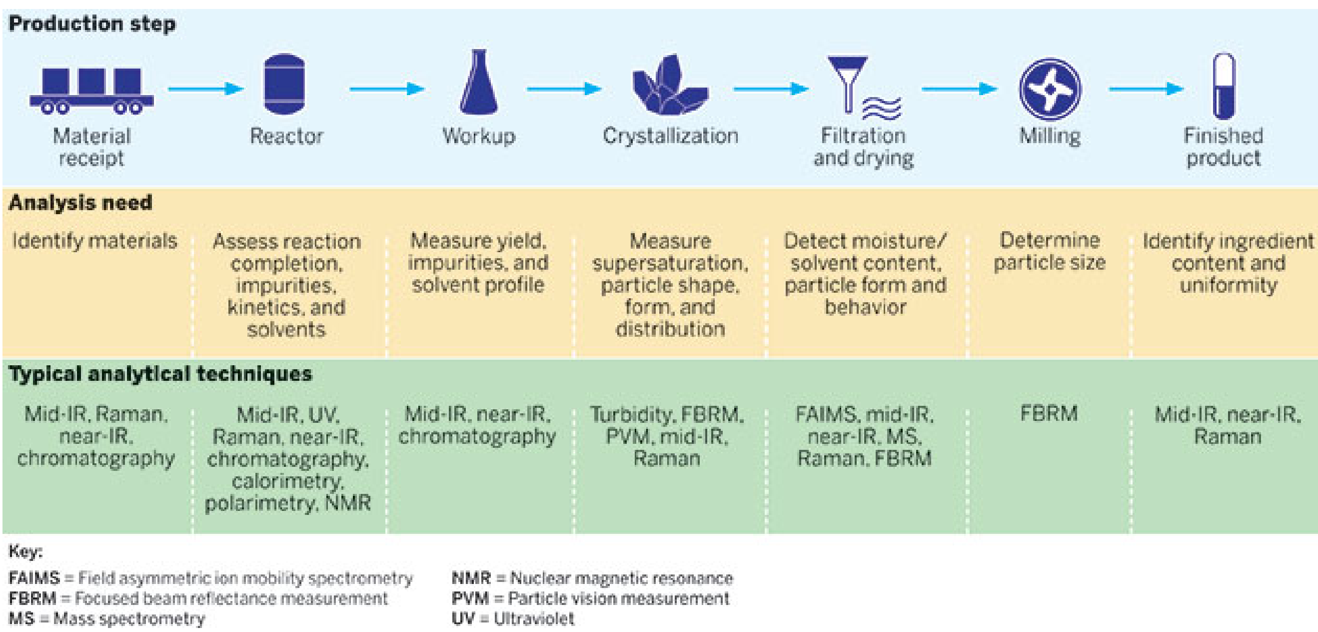

Figure 1: **Steps in drug manufacturing (as a proxy for a wide variety of chemical and biological industrial processes) call for different analyses and analytical technologies. SOURCE: Adapted from the International Consortium for Innovation & Quality in Pharmaceutical Development in *Org. Process Res. Dev.* 2014.**

Further, as noted in Figure 1 above, both Ultraviolet/Visible (UV) and Infrared (IR) spectroscopy play a pivotal role in the identification of structures along the entire technology path going from starting materials to finished products, particularly in industries producing bulk, feedstock and specialty chemicals, pharmaceuticals and bionanomaterials (artificial skin, for example). Our current IR devices are 12+ yrs old

(2), 8+ yrs old (2), and we have one that was installed in November using funds approved by the Committee last spring. While the four older machines do function, their ability to provide accurate spectra has diminished with age and either they need to be replaced or upgraded to be equivalent to the newest device. The two oldest devices have no upgrade path, so they must be replaced. Two devices can be upgraded to the quality of the newest device and we have requested funds to do so. We have also asked for six additional IR instruments to facilitate students' use of these in a manner that is consistent with the operational protocols in use in industrial and governmental laboratories; that is, samples are analyzed immediately after isolation, rather than after a wait time that is often up to 90 minutes (in CHM2211L labs.) Two upgraded devices in the instrument room and 12 additional devices placed in pairs in the individual laboratory areas will permit us to implement experiments that track a reaction's progress as a function of time. This experience is valuable for our students who will be involved in biochemical research as well as in medicine and pharmaceutical drug analysis.

In a similar situation, we have one UV spectrometer (pictured above). It is sufficiently old that no one knows exactly how old it is. Since it is running Windows 98 on the attached computer, we are guessing that is at least 18 years old. In addition, it has spent those years in an environment (an Organic Chem Lab) that is somewhat detrimental for any precision instrument. UV detectors are used either as stand-alone units or as devices integrated in chromatography systems. We propose to purchase two UV devices that are suitable for heavy use and have appropriate network connectivity for each of the six lab rooms. Adding the proposed units will enable Dr. Profeta to extend the use of UV evaluation methods by 50% in the lab experiments in CHM2211L. With the current single device, the protocols is that one sample is evaluated by a TA for his or her entire section. Having one or, preferably, two detectors in every lab will enable students to actually execute the procedures themselves. UV analyses are already part of each experiment in CHM4610L, where wait times even for a smaller number of students are 30 minutes or more. We will quickly implement experiments using both the IR and UV instruments for both the CHM2211L and CHM2200L labs, which we feel will invigorate students to have a more active interest in the concepts technology they are learning about.

Addition of Innovative Technology for Honors and Service Classes

As detailed in the article, *The Best Analytical Techniques for Testing Drugs of Abuse*, from Lab Manager, November 4, 2016, “Mass spectrometry (MS) has emerged as an everyday analysis tool suitable for screening and confirmatory analysis, and in some cases it blurs the distinction between the two.”

Desktop Mass Spectrometers are a relatively new development on the chemical instrumentation scene. Ironically, the Advion Company, a major supplier of such instruments, was tasked fifteen years ago by two former Glaxo (GSK) colleagues of Dr. Profeta to develop a Mass Spec device that they could place ‘in the fume hood’ in each of the laboratories where large chemical libraries were being synthesized. The drive for process efficiency was at the root of the request. Normal turn around time for a mass spectrum in the Glaxo labs had been 1 to 2 hours using the central MS facilities, which could be multiple buildings away. Even with the Advion prototypes, the timeline dropped to 30 minutes or less. Today, it takes 10 minutes or less for a researcher to know the mass of their sample using an Advion express***ion*** MS device. (See photo on next page.)

The Lab Manager article goes on to note:

“Drugs of abuse are in many ways, moving targets. Ne’er-do-wells with degrees in synthetic organic chemistry operate several steps ahead of the law; freelance compounders substitute substances not normally considered to be human medicines into street drugs. Thus, targeted screening may miss dangerous, illegal compounds such as synthetic cannabinoids and their derivatives or, as has recently been reported, heroin laced with elephant tranquilizers." *Unfortunately, reality in the domain of illegal drug synthesis, use, and abuse is as bad if not worse than portrayed in the 'Breaking Bad'* series (emphasis ours.) Local, State and Federal laboratories need more job-ready staff to assist in the protocols needed to analyze, synthesize and dispose of such toxic materials.

Figure 1 – TLC/MS system used in this work. On the left is the compact mass spectrometer with the PlateExpress extraction device and on the right is the isocratic pump (Advion, Inc., Ithaca, N.Y.). Individual TLC spots were extracted via an extraction solvent delivered from the isocratic pump shown underneath the PlateExpress. The extract from the TLC spot was delivered directly to the ESI or APCI source of the mass spectrometer, which provides a mass spectrum of the TLC spot. Shown here is the Advion expression CMS-L.

The bottom line is that without innovation, stagnation and incompetence creep into a curriculum. Our students need an exposure to, and at least minimal proficiency in, the technologies that will be critical to their endeavors as professionals-in-training. While the Upper-Level Analytical laboratory courses (whose facilities have been greatly enhanced by grants from the Tech Fee Committee) give students additional exposure to analysis methods such as UV and Mass Spectrometry, it is especially valuable for students to use MS as an integral part of a synthetic paradigm, so that they will understand how and why the tool is critical to the success of any given synthesis project. To this end, we are proposing the introduction of this critical technology to support both the Organic and Inorganic chemistry laboratory programs. The current generation of bench-top MS devices are easily integrated into each of the six laboratory rooms on the 5th floor of HTL. An example of one of the MS devices is given here.

New IR, MS, and UV instrumentation will allow both CHM2211L and CHM4610L curricula to be more aggressively developed to the benefit of our students. Experiments that are routine at Berkeley, Yale, Hopkins, Emory, Harvard, and, dare I say, UF, will be tractable, simply because we will have the instrumentation infrastructure that is needed to evaluate the progress and outcomes of the procedures.

As a footnote to this, Dr. Profeta has learned over his many years of interaction with equipment vendors that more UV spectrometers are sold to researchers in biology, nutrition & dietetics, pharmacology and toxicology than to research labs in all areas of chemistry combined. Given that the majority of the students we serve in Organic Lab are biology-related majors, it is indeed appropriate that we give them the practical experience of using this equipment.

Again, much of the equipment for these courses is either woefully outdated or students leave these labs without seeing some of the most common standard laboratory practices used in industry today.

Specifically, we request the following:

- **12 Digital Melting Point Apparatus**
  Name: Techne Stuart Digital Melting Point Apparatus with Programmable capability and +/- 1.0^{o}C accuracy.
  Price: $1,250.00 **Total: $15,000.00**

- **12 Stereo Zoom LED Microscopes**
  Name: Stereo Zoom LED Microscope with HD Digital Camera system and computer interface for evaluating crystal habits (polymorphic forms) of pharmaceutical agents, and inorganic complexes and metal-organic frameworks synthesized in lab.
  Price: $1,500.00. **Total: $18,000.00**

- **6 Programmable Microwave Ovens**
  Name: Programmable microwave ovens to facilitate chemical synthesis reactions
  Price: $1000.00 **Total: $6,000.00**

- **12 UV Spectrophotometers (routine, high-throughput devices)**
  Name: UV Spectrometers to provide UV analysis of compounds made in CHM2211L/CHM2200L & CHM4610L experiments.

Price: $7,000.00 **Total: $84,000.00**

- **6 FT-IR UATR Spectrophotometers (routine, high-throughput devices)**
  Name: IR Spectrometers to provide routine Infrared analysis of compounds made in CHM2211L/CHM2200L & CHM4610L experiments.
  Price: $25,000.00 **Total: $150,000.00**

- **2 FT-IR UATR Spectrophotometer Upgrades (routine, high-throughput devices)**
  Name: IR Spectrometers to provide routine Infrared analysis of compounds made in CHM2211L/CHM2200L & CHM4610L experiments.
  Price: $7,500.00 **Total: $15,000.00**

- **1 FT-IR UATR Research Grade System (for Honors sections of CHM2211L)**
  Name: Far-, Mid- and Near IR full FT-IR System with multi-bounce (3 or 7) Universal Attenuated Total Reflectance (UATR) diamond sensor capable of Pharmaceuticals and Materials analysis.
  Price: $55,000.00 **Total: $55,000.00**

- **6 Advion ASAP, TLC & Direct-Inject -express*ion*^{s} Compact Mass Spectrometers**
  Name: Compact Mass Spectrometers capable of analyzing solid, liquid and aerosol samples with molecular masses ranging up to 1200 amu. Systems will be used for reaction and structure analysis as well as for characterization of Pharmaceuticals and biological samples. Three different models give a range of input capability and the pricing covers 2 of each type, providing a broader Mass Spec experience for our STEM students.
  Price: $75,000.00 **Total: $450,000.00**

- **1 Digital Programmable Ultrasonic Bath (Honors Projects)**
  Name: Digital Programmable Ultrasonic Bath 1.5 L at 700 Watts for reaction catalysis with accessories. (Branson)
  Price: $1,750.00 **Total: $1,750.00**

- **1 Ultrasonic Cell Disruptor (Honors Projects)**
  Name: Digital Programmable Ultrasonic Cell Disruptor Immersible Sonicator for Reaction Catalysis with accessories and interface.
  Price: $6,500.00 **Total: $6,500.00**

- **1 Electrothermal Digital Melting Point Apparatus (Honors Projects)**

Name: Electrothermal Digital Melting Point Apparatus with computer interface and 32-bit processor; continuous programmable heat ramping capability with +/- 0.1^{o}C accuracy.
Price: $7,500.00 **Total: $7,500.00**

The grand total for updating and improving the CHM2200L, CHM2211L and CHM4610L courses is ~ $807,750.00

PART 2 – COMPUTER and VIDEO INSTRUCTIONAL SUPPORT

Required Computing Infrastructure (Organic Chemistry Labs)

Below is a summary of the hardware and software needs for the computing interface components to the new equipment in the Organic Chemistry lab rooms:

Hardware:

- 16 new Lenovo ThinkCentre i7 computers used manage new IR, UV and MS instruments and house structure and spectral databases used in analyses; 19" monitor, keyboard, mouse, MS Windows 10 w/Windows 7. Price per station from GovConnection is $1100.00; total request is **$17,600.00**
- 1 HP ProLiant Tower Server for DCs $1,427.14/server for 2X domain controllers comes to **$2,900**

Total Cost for Hardware: **$20,500.00**

Coupled with an upgrade to the equipment listed above, we also need to upgrade the laboratory network connectivity to allow for direct transfer of data from the equipment in the laboratories to the workstations, for backing up student data, and for allowing the students to access their data outside of the laboratory for further data analysis and report writing. Below is a summary of the cost that would allow for the installation of 5 wireless access points and 30 data drops to serve the interests of the students in the laboratories.

Network:

- Cabling Systems Installation Estimate: (Includes Voice, Data, Video, Security) **$10,073.81**
- Data Networking Equipment Installation Estimate: (Includes Wireless) **$7,739.36**
- 5% Contingency: **$890.66**
- Facilities Total Conduit/Pathway Estimate: **$25,000.00**

Total Cost for Network: **$43,703.83**

Video Equipment

While CHM2211L is not yet ready to deliver all lab manuals and pre-laboratory exercises via an online format, it is appropriate to move in the direction of video delivery of pre-lab concept reviews, and demonstrations of the assembly and function of many of the apparatus set-ups that are used in experiments. Such efforts have had good pedagogical results in General Chemistry Labs, CHM1045-6L and CHM1050-1L.

The project proposed herein would be virtually identical to the one proposed by Dr. Dillon in 2013-2014 and funded by the Committee. The cost of the video equipment will be a bit less due to our outfitting 6 rather than 8 lab rooms. The ancillary installation and construction costs are expected to be very similar, and we have made that assumption in our calculations.

Installation will most likely need to be done in phases, as all of the lab rooms are in use during all semesters. Thus, the scheduling of installations will need to be done during inter-semester breaks primarily. Bill Madden will assist us in such scheduling matters as he has capably done with construction projects in the past.

Video equipment estimate: **$37,500**

Installation, cabling, electrical, construction estimate: **$20,000**

Estimated total: $57,500.00

Summary:

We are requesting a significant upgrade and expansion in laboratory equipment coupled with enhancements in computing power and significant instructional infrastructure. The total request to completely update the General and Organic chemistry lab equipment and computer systems and to install video equipment for the Organic Labs: **$1,087,995.83**

These upgrades are critical to improving the job-readiness of our undergraduates. As stated above, in many cases, the equipment (including computers) is so antiquated that the instruction received on them is no longer relevant in today's industrial or government environments. Over 4,200 students pass through these labs annually and if we are to continue providing the type and level of training expected of STEM graduates and to continue offering Chemistry and Biochemistry as majors we have an obligation to utilize appropriate technologies and instruct students in a manner that best prepares them for the job market today. We cannot do that without these upgrades.

If funded, the equipment and software would be installed throughout the late spring and summer 2017 terms for full implementation and use in the fall 2017 term. Faculty training on the new equipment would be carried out over the summer 2017 term.

Faculty Making this Request:

Dr. Timothy Logan	Department Chair
Dr. Stephanie R. Dillon	Director, Freshman and Biochemistry Laboratories
Dr. Sal Profeta Jr.	Director, Organic and Inorganic Chemistry Laboratories