Final Report for Period: 09/2006 - 08/2007 **Submitted on:** 08/04/2007
Principal Investigator: Hawke, Scott D. **Award ID:** 0309546
Organization: Willamette University
Title:
Investigative Process & Technology in Introductory Physiology

Project Participants

Senior Personnel

Name: Hawke, Scott
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Tallman, John
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Stavrianeas, Stasinos
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Graduate Student

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Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)
The primary thrusts of the project are to introduce computerized data acquisition and investigative inquiry-based learning in Physiological Dynamics in Animals and Plants (PDAP). PDAP is a required sophomore-level introductory core course in biology. Additionally, there is the expectation to firmly embed the instrumentation in other physiology courses of the curriculum.

The running narrative below describes project activities and findings for three annual report years--2003-04, 2004-05, and 2005-06. The major accomplishments for 2003-04 were the purchase of bioinstrumentation

(Biopac), establishment of K-12 outreach, and development of a student assessment plan. The significant achievements for 2004-05 centered on student use of the data acquisition instrumentation, the implementation of student assessment, and a visit to Harvey Mudd College from where the model for this project award was adapted.

In September 2003, we (Hawke, Tallman, Stavrianeas) were awarded a NSF grant (#0309546) to accomplish the objectives stated above. During the fall semester 2003, we ordered and received Biopac instrumentation to accomodate students at eight laboratory work stations. Also, we began to develop assessment tools to qualitatively and quantitatively measure the impact of the laboratory program design and new technology on learning in physiology. During the spring semester of 2004 the Biopac system was introduced to students in PDAP and Human Physiology (HP) and limited assessments were made. Our experience with Biopac foreshadows a much more comprehensive assessment of the technology on student learning to begin in fall semester 2004. It is during the fall 2004 semester that two of us will visit Harvey Mudd College to learn how well a similar instrumentation program is working in biology. A visit
by an outside consultant (Dr. Mary Williams, Harvey Mudd) during the third year of the grant will provide evaluation of how well the program is operating for us. The consultant will make recommendations that can be implemented before the grant period expires in 2007.

In the fall 2004 (October 7), as an element of our professional development, the Co-PIs, Drs. G. Tallman and S. Stavrianeas, visited Dr. M. Williams of Harvey Mudd College. This was an important visit since our NSF-CCLI award is modeled after a similar program at her institution. At Harvey Mudd College the junior-level course, Comparative Physiology, is offered alternate years and is not required of all majors. It is team taught with a maximum enrollment of 12 students. There are six hours per week of student contact with one hour dedicated to 'discussion' and the remainder to laboratory work. Approximately two thirds of the lab time is committed to guided exercises. Assessments of student learning outcomes are mainly qualitative because of low student enrollments. In our implementation, the course, PDAP, is required of all sophomore biology majors, is team taught, provides three hours of laboratory time per week, and dedicates approximately 40% of the laboratory to guuided exercises. Our maximum enrollment is 32 students and the course is offered twice a year. The laboratory time is complimented with four 50 minute lectures to include one laboratory recitation. Student learning outcomes in our progam are quantitatively assessed. Although there are differences between Comparative Physiology at Harvey Mudd and PDAP at Willamette, the similarities to note are:

1) Many of the same types of experiments are carried out in both courses using similar types of equipment.
2) Both courses require students to develop an independent, investigative research project.
3) Student-faculty communication is frequent to keep projects on track.
4) Both institutions have modern, well-equipped laboratories to support the laboratory work.

It should be noted that a major advantage of our grant compared to the one awarded at Harvey Mudd is we have an assessment process in place to evaluate student learning outcomes statistically. This quantitative measure is possible because of our large enrollments.

In winter 2006 (January 24 and 25), Dr. M. Williams of Harvey Mudd College visited Willamette to assess PDAP and make recommendations to further improve the physiology program. Her comments were most laudatory with two suggestions for further strengthening the laboratory expeience. She wished to see a greater cultivation of formulation and testing of hypotheses as a component of all laboratory activities, including the structured labs that place a heavy emphasis on learning new techniques. Also, Dr. Williams observed that lab reports need to focus more clearly on developing scientific writing skills to enhance the communication of ideas. On the other hand, Dr. Williams was particularly impressed to understand the CCLI award for PDAP in Biology also impacted student learning in Human Physiology and Physiology of Exercise. Additionally, Dr. Willliams was pleased to recognize the original CCLI award for PDAP has led to a second successful CCLI grant to further develop laboratory investigations in Physiology of Exercise.
It is most satisfying how well our success in PDAP has disseminated to other courses in another department. The full text of her review is attached as a pdf. file.

Findings:

A quantitative assessment of Biopac use and the ability to use the newly acquired technology to interpret physiological studies was implemented at week 12 for students enrolled in Human Physiology (HP) during spring semester 2004. The evaluation used contains five Student Learning Objectives (SLOs), some with more than one goal. The SLOs can be viewed at our Web site (http://www.willamette.edu/cla/biology/biol244/index.htm) as noted in the dissemination section of this report.

The overall mean response of students to the SLOs in HP was clearly below the mid point (2.50) of our four point scale ranging from 1.12 for the student has learned computerized data acquisition skills to 3.53 for the student can recognize limitations in experimental designs and methods. The less than satisfactory scoring level to all but one of the SLOs was surprising considering this evaluation was conducted during the last quarter of the course. There is no easy explanation other than it may take more than one semester of computerized data acquisition use and immersion in scientific problem solving. The students appear to be relatively naive in their ability to comprehend the scientific process using Biopac as a tool to achieve this objective.

The assessment plan for fall semester 2004 is to implement the SLOs for two other physiology courses, PDAP and Animal Physiology (AP). Additionally, there will be multiple evaluations, i.e., self evaluation at weeks 1 and 15, peer evaluation at week 15, and faculty evaluation at week 15. It is hoped these additional evaluations from several different coherts will provide a clearer explanation of how well our Biopac instrumentation is translating in our physiology courses.

In the spring of 2004 16 students in PDAP and HP responded to a qualitative assessment of Biopac by accessing the web site (http://www.willamette.edu/~stas/nsfevaluation.htm). The salient conclusions were:

-the majority of students had not previously used digital data acquisition systems;

-the students all indicated they gained confidence in use of the Biopac system in their investigative class projects, although only a minority of the respondents actually did;

-the availability and ease of use of Biopac did not appear to influence their choice of investigative projects suggesting the student choices were driven by personal interests that transcend electronic recording;

-students, with one exception, acknowledged Biopac provided reliable data outputs and laboratory instructions were easy to comprehend

A concerted effort will be made next semester (fall 2004) to have the majority, if not all, students respond to the web-based evaluation. Only 16 of 43 students responded to the evaluation. A greater number of respondents reporting will give us a clearer picture of the impact of the Biopac system on our undergraduates in physiology courses.

The evaluation instrument for SLOs was implemented more fully during the 2004-05 academic year. Only those students in HP and PDAP were surveyed. Students in AP were not included in the assessment because many of the laboratories do not utilize the Biopac equipment, but other methodology. Instead of students responding to the SLOs on our web site, we had the students respond on paper copy provided during the appropriate laboratory sessions, i.e., weeks 1 and 15. This approach elicted a response from virtually all students in HP and PDAP.

In HP all students (29 in two semesters) showed self-report progress comparing intial and end of the semester responses. Peer review showed students were more generous with their comments about their partners than themselves. Instructor comments were less complimentary, but this result is predictable based on higher levels of expectation. From these data one can conclude that students were fair in their assessments of Biopac on their learning, and that the assessment instrument reflects the same priorities and qualities in students and instructor. The results were equally pleasing from the student satisfaction survey using Biopac equipment. Based on student responses, it is evident the laboratory experience using Biopac was an integral part of their success, e.g., all students agreed or strongly agreed the utilization of Biopac instrumentation gave them a better understanding of physiology and an equal number of students indicated the Biopac system enhanced their learning of physiology. For reasons not immediately apparent, 80% of students in the first semester used Biopac for their investigative studies while only 15% did so during the second semester.

In our introductory physiology course, PDAP, student outcomes (50 students in two semesters) were comparable to the responses recorded for students in HP. As expected, self reports comparing first and final laboratories, showed improvement. Students were more capable of scientific problem solving, enhanced demonstration to critically dissect experimental designs, greater effectiveness in data analysis, and increased capability to draw reasoned conclusions. Although physiology is a challenge to comprehend, the students were better able to make connections between animal and plant physiology. As we say, 'a cell is a cell is a cell,' no matter where we find it. Peer evaluation of laboratory partners was somewhat mixed while faculty evaluation was definitely less generous but fair. The assessment instrument clearly revealed that the laboratory experience using computerized data acquisition enriched student understanding of physiology and helped them to 'think' more like a scientist. The student satisfaction survey using Biopac technology revealed students were overwhelmingly pleased (80-90% agreed or strongly agreed) with the equipment. The Biopac system helped students to become familiar with how technology can be used in problem solving and helped them to overcome their fear of using instrumentation in the laboratory. However, less than half of the student groups used Biopac in their investigative studies, despite introducing an animal-based laboratory, i.e., frog heart contraction cycle. It is

curious that many of the students want to do group projects that focus on metabolic responses of mice to drugs.
These studies are not accomodated by Biopac, but can be done with Vernier and Qubit systems. Also, a number of student groups do plant studies that do not utilize the Biopac system.

At the end of the 2005-2006 school year, the stuent learning outcomes of approximately 180 students in PDAP and HP have been recorded using our assessment instrument. We expect at the completion of the next academic cycle (2006-2007) to have enough student responses to analyze and to publish a paper in an education journal. Our educational consultant, Dr. John Tenny, will be involved in helping us interpret the findings. The assessment, as noted earlier, is described in detail on our PDAP website.

Training and Development:

The PI/Co-PIs involved in this project were favorably impressed with Biopac instrumentation after three semesters of its use in two lower division physiology courses--Physiological Dynamics in Animals and Plants (PDAP) and Human Physiology (HP). We were amazed how well the students adapted their limited laboratory skills to the use of Biopac. The students were not intimidated by using the data acquisition equipment for the first time. The ease of use, i.e., a 'plug and run' approach and easily understood documentation allowed the students to begin operating the equipment independently in a short period of time.
As faculty we were immensely pleased how well the students reacted to this new laboratory experience. All experiments involved use of human subjects. Animal experiments are planned for the 2004-05 academic year. The animal studies are much more challenging to conduct. It will be of interest to observe how well our students respond to the introduction of animal preparations.

In the past two years the use of animal preparations, e.g., frog sciatic nerve, gastrocnemius, and heart preparations have been highly successful. The dissection, setup, and use of the Biopac electronics worked exceedingly well. In fact, many of students preferred the animal preparations to working with the noninvasive studies done on their own bodies. The live animal tissue/organ models can be somewhat unpredictable, but exciting to work with despite the difficulties.

As compelling as Biopac instrumentation is to use, we were somewhat surprised so few students in PDAP wished to use the technology in their investigative studies. This was partially true in HP where the focus was strictly on the human model. Perhaps the absence of animal use in PDAP early on limited student enthusiasm for using Biopac. This interpretation proved to be correct. With the introduction of animal preparations in 2004-05, electronic recording of animal physiology developed a cache for investigative studies.

Surveys over two years of our undergraduate teachers using Biopac in the Saturday Explorations in Advanced Science (SEAS) and one year in Willamette Science Outreach Program (WSOP) revealed little change in regard to their interest in teaching public school children. However, they developed a greater understanding of what is involved in teaching students in K-12. Some were discouraged by the amount of work involved in effective instruction or were disappointed by disinterested students. Despite mild discouragement, they were all intrigued by the challenge. The emphasis on investigation over calculation and immediate feedback with Biopac had a positive influence on children's interest in scientific inquiry.

Outreach Activities:

There are two target audiences for the dissemination of our Biopac technology into the wider community of K-12. They are Saturday Explorations in Advanced Science (SEAS) and Willamette Science Outreach Program (WSOP). Both programs utilze biology majors as trained teaching assistants (TAs) for the implementation of the Biopac data acquisition system. The undergraduate TAs design laboratory protocols and direct their use for the SEAS and WSOP students.

This past winter (January-March 2004) on separate Saturdays 75 students in SEAS were introduced to our new Biopac system as one of five different science activities. These students were identified primarily as talented and gifted in grades 5-8. The students were exposed first to a variety of experimental designs from EKG to respiratory cycling. Then the students were given the freedom to modify the experimental schemes and come up with their own hypotheses. The result of their efforts were exciting and meaningful. For the first time these young science minds began to think like scientists by making educated guesses as to findings and 'tweaking' the designs to further refine the outcomes. Of all the science activities in the SEAS agenda, the data acquisition study using Biopac electronics was overwhelmingly the most popular and highly rated. After five Saturdays with students engaged in different science activities, the students evaluated their experiences and selected which of the five science immersions they would like to return to for an extended lesson on the sixth and final Saturday of the program. The Biopac lesson was selected by 34% of the students as a first choice and 22% picked it as their second choice. Evidence is strong, therefore, that the Biopac system significantly piqued the interest of these young students. Once again, during the winter school term of 2005, SEAS students were provided the opportunity to work with Biopac equipment. As was true in the previous year, the grade school students rated highly the experience. The Biopac system engaged he students because it focused on their body physiology. It was a personal-types experience that transcended science theory.

It is of interest that the Biopac company contacted the PI after reading the annual report in 2004. The company asked us to 'try out' a hand-held A/D converter (MP40) that could be affordable in the market place of public schools. The device with attached electrodes allowed for non-invasive measurement of electrical signals, i.e., EKG, EEG, and EMG. Ths was clearly a 'plug and run' type of operation that would cost approximately $300-400 per unit. My student assistants used the device and found that the harware configuration (except for flimsy electrode clips), documentation, software usability, and basic functionality were superb. The downward trickle of this type of technology into the public school sector is to be applauded.

In July 2004 and audience of WOSP students (20) in grades ranging from middle through high school were invited to use the Biopac instrumentation. This group of students was primarily of minority ethnicity who indicated a strong perference for learning from the arts to the sciences. Again, with a group of young students more diverse those of SEAS, the use of the Biopac system was an outstanding success. More the half the students considered the science exposure as their most exciting and meaningful experience. I suspect the 'hands on' approach of recording signals from their own bodies is what captured their enthusiasm for electronic recording with Biopac. Unfortunately, another annual session using Biopac is not scheduled for WSOP students in July 2005.

In the current report year of 09/2005-09/2006 the K-12 outreach component of the NSF-CCLI award using Biopac instrumentation is still viable. Last fall and early winter two exercise science majors and two biology majors, respectively, engaged students (grades 5-8) in the Saturday Explorations in Advanced Science (SEAS). The students used the electronic hardware to study the physiology of the human body. The students devised hypotheses and tested them on measurements recorded from skeletal and cardiac muscle. The students were amazed by the instantaneous data displays of electrical conduction and contraction behavior of their muscle tissues. They left the laboratory with a ewnewed enthusiasm for doing science beyond the paper/pencil exercises they commonly encounter in a public school setting. As the students said, 'the experience was awesome!' In addition, we had a number of high school and middle school students visit our laboratory. More specifically, we hosted more than 200 students from six local high schools and two middle schools. Again, they used the Biopac equipment in a variety of muscle tension experiments. One of the science teachers in attendance said, 'it was such a positive experience that even a month later the students mentioned something that happened in the lab at least onece a week.' In fulfilling our pledge to NSF for an effective outreach program, we feel are making a difference in science education in the broader Salem community.

Journal Publications

Scott D. Hawke, Stasinos Stavrianeas and Gary Tallman, "Investigative Learning in Introductory Physiology", Council of Undergraduate Research (booklet on inquiry-based laboratories), Dr. Kerry Karukstis, co-editor, Harvey Mudd College, p. , vol. , ( ). Accepted,

Hawke, S.D., Stavrianeas, S., and Tallman, G., "An investigative laboratory for integrated plant and animal physiology at the sophomore level", Proceedings of the Oregon Academy of Science, p. 11, vol. XLIII, (2007). Published,

Hawke, S.D., Stavrianeas, S., and Tallman G., "An investigative laboratory for integrated pland and animal physiology at the sophomore-level at Willamette University.", Plant Biology, p. 48, vol. 54, (2007). Published,

Books or Other One-time Publications

Web/Internet Site

URL(s):

http://www.willamette.edu/cla/biology/biol244/index.htm

Description:

The Web site has a submenu or sidebar titled NSF-CCLI. It describes the purpose of the technology grant to establish computer-based data acquisition in the physiology laboratory. It also highlights the self, peer, and faculty evaluation of student learning. The evaluation forms represent quantitative and qualitative assessments that can be accessed and responded to by students and faculty. NSF is clearly acknowledged for its support.

Other Specific Products

Contributions

Contributions within Discipline:

The anticipated publication of Investigative Learning in Introductory Physiology by The Council on Undergraduate Research provides a model of how to effectively team teach animal and plant physiology with inquiry-based investigative studies highlighting the laboratory experience. A formal assessment process is described how to successfully measure expected student learning outcomes for doing physiological investigations.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Categories for which nothing is reported:

Organizational Partners

Any Book

Any Product

Contributions: To Any Other Disciplines

Contributions: To Any Human Resource Development

Contributions: To Any Resources for Research and Education

Contributions: To Any Beyond Science and Engineering

Biopac® Science:
Teaching the Cardiovascular System to Elementary and Intermediate Students

Christopher McNeil. August 15, 2007. Willamette University.

For the spring 2007 session of Willamette University's Saturday Exploration Program I instructed a laboratory based lesson on the cardiovascular system using Biopac Student Lab. The sessions were held for two hours on Saturdays for five consecutive weeks. Each week a different group of fifth to eighth graders in the Math/Science rotation participated. Class sizes averaged from 6 to 10 students. The students worked in pairs at iMac computer stations that were equipped with a Biopac MP30 Acquisition Unit, Biopac electrode lead set (SS2L) and Biopac pulse plethysmograph (SS4L). During this lab students were encouraged to experiment with variables that could affect the cardiovascular system and then utilizing Biopac Student Lab software to analyze and explain their recorded physiological data.

First, I had each group familiarize themselves with the heart using a simple interactive program with drag and drop labels for anatomical structures.[1] They then opened another animation that allowed them to see the sequence of events in the cardiac cycle, including the contraction of chambers, the flow of blood through the cardiopulmonary circuit and the opening and closing of valves with accompanying audio of the characteristic "lubb-dubb" rhythm heard through a stethoscope.[2] Next, I had each group play a Shockwave® animation of the cardiac cycle in slow motion that included synchronized side charts depicting the stages of systole and diastole, blood pressure, heart sounds, and the waves of an electrocardiogram.[3] Lastly, to emphasize the temporal separation between the atria and ventricles the students watched a color coded animation depicting the progression of depolarization and subsequent repolarization throughout a cardiac cycle.[4] Once students showed an understanding of how the heart's anatomy and physiology permit electrocardiography they were instructed on how to make their own electrocardiograms (ECG).

Each pair of students alternated between operating the computer and being a test subject. I explained that the body contains fluids with ions that enable electrical conduction, which in turn make it possible to use legs and arms as convenient extensions for gathering electrical signals originating from the heart. Using one student as a model I showed the groups how to establish a lead angle to record the difference in magnitude between the positive and negative electrodes of the SS2L electrode set. Three Biopac disposable vinyl electrodes were used per test subject. The students connected the White (-) lead on the palmar side of the right forearm, near the wrist, and the diametric Red (+) lead on the medial surface of the left leg, just above the ankle bone. Next, they established the ground wire above the medial side on the right ankle to act as a reference and securely fastened the electrode cable clip to a garment to prevent the wires from being pulled on during experiments. Lastly, the subject attached the SS4L pulse transducer around the tip of his or her index finger on the right hand. Students were asked to explain what might happen to their readings if the transducer were wrapped too tightly or loosely.

The computer operator then opened Biopac Student Lab Lesson 7: ECG & Pulse and entered the test subject's name. When prompted to calibrate the ECG and Pulse waveform channels, I had the operators record a 10 second span of data while the subjects waved or tapped the fingers of their right hands. The students were asked to explain why their data peaks appeared erratic, had baseline drift, or flat lined. I followed with a discussion on the importance of relaxing their muscles during recording to minimize extraneous electrical interference, limiting movement of sensitive recording devices, and adequately fastening equipment to attain a reading. I stressed the significance of trying to control these variables throughout their experiments so data could be accurately compared. Once the students had collected an acceptable calibration they preceded to record data for a series of different experimental conditions by appending 15 to 20 second waveform readings to their data windows. The groups were permitted to carry out their experiments in any order they desired with the explicit obligation that they remember the sequence. Possible testing variables included: submerging the subject's left hand in plastic tubs of hot and cold water, holding their right hand above their head or while hanging down to their side, recording while prostrate, sitting, or standing, or following exercise, rapid breathing, laughing, or holding one's breath. When the first subjects' experiments were completed their data was saved and they switched turns with their partner as computer operator.

Some student teams finished earlier then others due to variability in the efficiency of each group and their freedom to choose the experiments they performed. This enabled me to stagger and individualize my instruction on how to analyze and extract meaningful quantitative measurements from recorded data waveforms. As time permitted, I challenged the groups to formulate physiological explanations accounting for differences between experiments that they found particularly interesting or to label the P,Q,R,S, and T peaks of their ECGs and correlate them to the corresponding events of the cardiac cycle. By not restricting the speed or focus of each group's experimentation I found that they assumed a more engaged and intellectually productive understanding of the lab. I asked my last group of students, who were mostly in seventh grade, to write down what they thought about the experiment and equipment. All the responses were very positive. One girl wrote "This lab was extremely fun. It was scary at first but I got over it, and I learned a lot. This lab was so much cooler than I thought it would be!" Another student responded, "This was the best class so far. It was amazing how we could see how certain things affected our pulse, our heart rate, and other things. Also, these computers were really cool and helpful to this amazing and cool learning opportunity."

By the end of our two hour session most of my students could explain the difference between arteries and veins as well as correctly describe the sequence of the cardiac cycle using accurate anatomical descriptions and physiological explanations, including: systole, diastole, depolarization, and repolarization. Many could also link cardiac events to changes in elasticity and contractility of the vascular system and use vasodilatation and vasoconstriction as explanations to account for temperature's effect on heart rate and pulse. In my opinion, the student's ability to quickly grasp these concepts arose from having interactive models to mentally reference, while their aptitude in correctly applying physiological explanations was strengthened by the logical analyses of their intuitive experimentations.

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[1] Bishop Stopford School. 2007. Heart Drag & Drop. <http://www.bishopstopford.com/faculties/science/arthur/Heart%20drag&drop.swf>. Accessed 2007, May 20.

[2] Guidant Corporation. 2007. Blood Flow Through Your Heart and Lungs. <http://www.guidant.com/condition/heart/heart_bloodflow.shtml>. Accessed 2007, May 20.

[3] Blumenthal, D. 2007. HyperHeart. <http://library.med.utah.edu/kw/pharm/hyper_heart1.html>. Accessed 2007, May 20.

[4] Electrical Depolarization & Repolarization of Heart. 2007. <http://www.cesinst.com/Animations/Normal/>. Accessed 2007, May 20.

Williamette University's NSF CCLI-supported physiology curriculum

On January 24th and 25th (2006) I visited the Biology Department at Willamette University. During my visit, I met with faculty and students who have participated in courses supported by the NSF-CCLI award number DUE-0309546. I attended a laboratory session for one of the courses and learned more about the other two by discussions with students and faculty. The equipment purchased by the CCLI award impacts courses required for two different majors at Willamette University. "PDAP" (Physiological Dynamics of Animals and Plants) is a sophomore-level course required for the Biology major. Human Physiology and Physiology of Exercise are required for the Exercise Science major.

Physiological Dynamics of Animals and Plants

The PDAP course is designed to break down the barriers between animal and plant physiology. The course is structured so that each topic (such as energy transduction or nutrition) is taught sequentially from animal and plant perspectives, with PIs Hawke and Tallman alternating lectures. This approach towards synthesizing animal and plant physiology is non-traditional but very effective. I have talked to several faculty at other institutions who wish to move their physiology course material in this direction but fear that it will be too difficult to coordinate the teaching, or that students are not sophisticated enough to appreciate the comparisons. (Nancy Pruitt and I discussed this challenge at length during her visit to Harvey Mudd College in April of 2005). Clearly, Willamette University has developed a successful model for incorporating both plant and animal physiology into a single course.

The PDAP lab also integrates investigations into plant and animal physiology throughout the semester. Students are divided into a Wed or Thursday lab section which meets every week. Both Hawke and Tallman reserve Wed and Th afternoons for lab, and the instructors alternate lab days each week. For example, in Week 1, Hawke teaches an animal module on Wed and Tallman a plant module on Th, and in Week 2 Tallman teaches the plant module on Wed and Hawke the animal module on Th. Two separate teaching laboratories are used, so the equipment can be set up once and not disturbed while both lab sections cycle through the module.

After 6 weeks of fairly prescribed lab exercises, the remainder of the semester is dedicated to independent student projects. Students self-assemble into three- or four-person teams, which work together to select a topic, do a literature review in their chosen field, set up a time-line for their project and carry it out. The teams report on their project through an oral report in a research symposium, and each student individually writes up a lab report.

The students I spoke to were universally enthusiastic about PDAP. Several indicated that the format of the course helped them appreciate the connections not only between plant and animal physiology, but also between cell biology and ecology. The students also praised the format of the mid-term exams, which require integration and synthesis of material rather than rote memorization.

Students were universal in praising the independent project component of the lab course. They felt that the exercises during the first six weeks prepared them for the independent project by exposing them to a variety of types of instrumentation and physiological concepts. Students volunteered that they had worked very hard on their projects, from coordinating their project management efforts to identifying a project, reading up on the relevant literature and tinkering with their experimental designs. One student said, “The project required a better and deeper understanding of the material than ever before in our courses”.

I had lunch with ten students who had previously taken the PDAP course. At one point I asked them to go around the table and tell me about their project in “one or two sentences”. Each student spoke for several minutes, telling me about the justification for the experiment, the experimental design and controls, and their results and interpretation of the results. The students were **very** enthusiastic as they described their projects and clearly showed pride in their accomplishments. The level of detail with which they described the projects was also impressive, considering some had completed the projects nearly a year ago.

Human Physiology and Physiology of Exercise

The equipment purchased through the NSF-CCLI award is also used in two courses taught by co-PI Stasinos Stavrianeas. Both the Human Physiology course and the more advanced Physiology of Exercise course incorporate modules using the CCLI-funded equipment. Recently, Stas has been awarded another CCLI grant to further develop the advanced course, which follows the successful PDAP model by culminating in an independent student project. Clearly, the CCLI award has had a broad impact at Willamette, substantially impacting three separate courses. I’m encouraged to see that this original CCLI award has led to another successful NSF-CCLI award and that the good ideas implemented into PDAP are disseminating into additional courses at Willamette University.

Impact on student research

Willamette University is in transition towards increased faculty participation in research. The curriculum is also changing to better prepare students for senior research projects. It is clear from talking to students that the independent projects they carried out in PDAP helped them prepare for subsequent research projects. The equipment is simple enough that after using it in defined modules in the early part of the semesters, students were able to use it successfully in their independent projects. Importantly, they could focus their efforts on learning about experimental design and analysis rather than on the instrumentation. This opportunity to engage in independent research is clearly engaging students and generating enthusiasm to pursue additional research opportunities. One student I spoke to is even continuing her PDAP projects as her senior research project.

Outreach

The PIs have successfully incorporated experiments using the equipment purchased by the CCLI award into two ongoing outreach programs at Williamette University. In the

"Saturday Exploration in Advanced Science" program, public school students (grades 5 – 8) attend classes at Willamette over several Saturdays during the academic year. The "Willamette Science Outreach Program" is a similar program targeted at middle through high-school students that takes place in the summer. In both of these programs, the classes are taught wholly or in part by Willamette undergraduates. Thus, not only do the participating younger students get exposure to science, but the undergraduate science students get exposure to teaching. The specific modules developed through this CCLI award use the BioPac equipment. The classes take place in the Willamette teaching laboratory classrooms. Using the BioPac equipment, students learn how a scientist studies the human body. The material is accessible to the younger students because the concepts are already familiar; what is new is how the familiar material is presented. For example, the students are already aware that their heart rates increase with exercise; the equipment allows them to **visually observe** and **measure** the increased rate. This is an engaging approach through which students get to explore their own bodies and at the same time see how a scientist views the same subject. I was impressed by the institutional support of the outreach program; the PIs were able to put their efforts into developing an effective learning experience rather than trying to create a structure with which to disseminate it.

Suggestions for future directions

I was very impressed by the Biology program at Willamette University and the positive impact of the NSF-supported PDAP course. There are two minor areas in which I felt the lab could be strengthened. Both are currently being addressed by the instructors, but I want to encourage them to continue with their efforts in these directions.

Formulating hypotheses

The process of doing science by formulating and testing hypotheses is introduced in the PDAP course and increasingly emphasized as the semester progresses. I would encourage the PIs to modify the lab structure so that formulating and testing hypotheses is *integral* to all the exercises from the beginning of the course. A simple shift in the way a problem is presented can change an experimenet from a demonstration to an inquiry, and so get the students more engaged in the outcome. For example, in the first week of the sophomore lab course at Harvey Mudd the students generate a standard curve of *para*-nitrophenol, which they subsequently use in an enzyme kinetics lab. Even though the purpose of the first week's exercise is to help students learn how to use the spectrophotometer and pipettors, we frame it so that they are testing the hypothesis that "Absorbance is linearly proportional to concentration" (Beer's Law). After the students graph their data, we ask them if their data support their hypothesis. By always adhering to this structure, we try to get students into the habit of designing their experiments around testable hypotheses.

Scientific writing skills

The second area in which the PIs can strengthen PDAP is the format and structure of the written lab reports. The level of sophistication of the lab reports has increased as the instructors have increased their expectations, and I would encourage them to continue in this direction. This suggestion comes from my involvement in teaching the required sophomore lab course at Harvey Mudd in which learning to write a formal "journal-style" lab report is a primary objective. By emphasizing scientific writing in this particular required course, we are able to remove some of the emphasis on teaching writing skills from our upper level and elective courses. By analogy, PDAP seems to be an ideal course in which to emphasize scientific writing skills. We assign the book "*A Short Guide to Writing About Biology*" by Jan Pechenik as a required text for our class, and spend some time in class talking about the content and structure for each lab write up. We encourage peer-review and consultation with Writing Center consultants, but also read and comment on a first draft prior to the graded lab report. Although increasing the emphasis on helping students develop their writing skills can increase the faculty workload, the effort does pay off in that less writing instruction needs to take place in subsequent courses.