ONLINE ARTICLE

Learning Benefits of a SUMMER RESEARCH PROGRAM at a Community College

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Abundant evidence indicates that undergraduate research significantly benefits students by encouraging them "to develop skills and interest in scientific fields by allowing them to perform a role they do not yet occupy" (Hurtado, Chang & Chang, 2005). One clear result is that undergraduate research increases graduation rates (Russell et al., 2007) and encourages students to pursue science careers (Hathaway et al., 2002; Lopatto, 2004). However, while undergraduate research in molecular biology is offered at many four-year schools, this opportunity is less common at community colleges and there is little research data on the efficacy of research programs at such schools.

We recently conducted a Student Assessment of Learning Gains (SALG) survey at Borough of Manhattan Community College among students who had participated in mentored research projects. In all ten categories examined, 80-90% of the students agreed that their research experience had been of great benefit, increasing their academic ability and confidence in science, and heightening their general interest and enthusiasm for a possible scientific career. However, we did not have any empirical evidence that they had benefited intellectually from this experience. In an effort to accrue data on student learning gains from a research experience, we designed a five-week summer program – the BMCC Summer Research Initiative – in which participating students were taught basic molecular biology and tissue culture techniques. At the end of an initial three-week training session, students conducted short research projects. Here we report on the outcomes of the program.

Student Selection

Twelve students participated in the program, selected from the Science Department at BMCC. Students were required to have a GPA of 3.0 (or a recommendation from a professor in the case of a GPA between 2.5 and 3.0), to have previously completed at least one biology course, and to write a 300-word essay explaining their motivation for applying to the program. Applications were vetted by three professors involved in this program. Academic credit was not available for summer program participation so students were given a stipend. Student demographics are presented in Figure 1.

The described program ran for five weeks during a 2007 summer session at the college. We gave the class a basic laboratory course, as well as training in molecular biology and tissue culture (Table 1). The basic laboratory course included laboratory safety, laboratory equipment and use, and general laboratory procedures, such as making solutions and creating a standard curve. In the tissue culture component, we taught students how to grow and maintain mammalian cells, how to count cells using a hemocytometer, and how to carry out a cell growth curve analysis. We used HeLa cells (cervical cancer cell line kindly donated by Dr. C. DeLemos-Chiarandini, NYU School of Medicine, NY) and DLD14 cells (colon cancer cell line kindly donated by Dr. B.

Figure 1. Summer program student demographics. Twelve students were selected from an applicant pool of 45. Selected students fulfilled the criteria outlined in the Student Selection Section above.

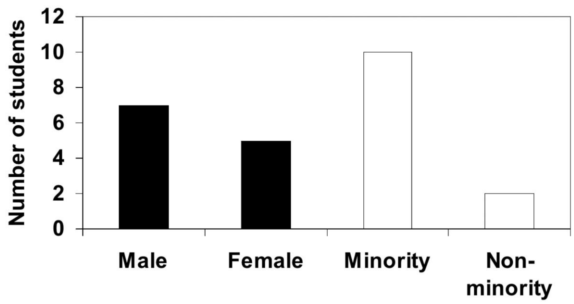

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Table 1. Program outline: Details of experimental procedures, tutorials, case studies and exercises used in the summer program.

EXERCISE	PROCEDURE	PROTOCOL/SOURCE
1.	• Introduction to lab safety and equipment use • Revision of laboratory mathematics • International measuring units • Literature searches	• Worksheets on understanding and solving problems with SI units • "Knowing the tools of the trade" exercise[a] • Library and PubMed[b] exercises to familiarize students with scientific resources
2.	• Micropipetting • Making solutions	• Worksheets on making laboratory solutions
3.	• Basics of tissue culture (growing and counting cells; growth curves) • Reading a scientific paper • Theory of experiment design • Designing and conducting a simple experiment	• Tissue culture protocol practiced with colored water solutions • "How to read a scientific paper"[c] • "Experimental science projects: an introductory level guide"[d] • Bacteriology experiment based on "The Five Second Rule Explored or How Dirty Is That Bologna?"[e] • Case study on experimental design[f]
4.	• Start tissue culture with HeLa cancer cells • Protein extraction and quantification	• Total cell protein extract using Laemmli sample buffer • BCA protein quantification[g] • HeLa cells cultured, counted, subdivided, and frozen
5.	• SDS-PAGE • Coomassie staining • Western blot	• Total cell protein electrophoresed on pre-made 12% tris-glycine gels • Protein Profiler Kit[h]
6.	• Extracting genomic DNA • DNA restriction analysis • DNA agarose gel electrophoresis	• Extracting DNA from fruit smoothies[i] • DNA Fingerprinting[j]
7.	• Principles of PCR	• PCR control reaction[k] • Crime Scene Investigator Kit[l]
8.	• ELISA	• ELISA Immuno Explorer Kit[m]
9.	• Research project	• Details in Table 2
10.	• Writing a scientific report	• "Writing a scientific research article"[n]

[a] Lee, P. (2000). Available online at: http://csmp.ucop.edu/downloads/csp/know_tool.pdf.

[b] PubMed. http://www.ncbi.nlm.nih.gov/entrez/.

[c] Little, J. W. & Parker, R. (2006). How to read a scientific paper. Available online at: http://www.biochem.arizona.edu/classes/bioc568/papers.htm.

[d] Morano, D. (1995). Experimental science projects: an introductory level guide. Available online at: http://www.isd77.k12.mn.us/resources/cf/SciProjIntro.html.

[e] McGee, H. (2007). The Five-Second Rule Explored or How Dirty Is That Bologna? *New York Times*, May 9, 2007.

[f] Herreid, C.F. (2001). Mom always liked you best: Examining the hypothesis of parental favoritism. Available online at: ublib.buffalo.edu/libraries/projects/cases/coots/coots.html.

[g] BCA™ Protein Assay Kit. Pierce. Rockford, IL.

[h] Protein Profiler Kit. BioRad. Hercules, CA.

[i] Seidman, L. & Mowery, J. (2006). The Biotechnology Project: DNA from fruit smoothies. Available online at: http://www.matcmadison.edu/biotech/resources/activities/**dna**/student.htm.

[j] DNA Fingerprinting Kit. BioRad. Hercules, CA.

[k] exACTGene Complete PCR Kit. Fisher Scientific. Rochester, NY.

[l] Crime Scene Investigator Kit. BioRad. Hercules, CA.

[m] ELISA Immuno Explorer Kit. BioRad. Hercules, CA.

[n] Alley, M. (1996). Writing a scientific research article. From *The Craft of Scientific Writing*. Available online at: http://www.columbia.edu/cu/biology/ug/research/paper.html.

Table 2. Research projects. Students participated in one of two ongoing research projects in our laboratory. Both projects require that students are familiar with a variety of techniques taught in the training part of the summer program.

PROJECT BASIS	TECHNIQUES REQUIRED
1. Examining the molecular effects of butyrate on cancer cells 2. Examining the molecular effects of omega-3 and omega-6 short chain fatty acids on cancer cells	1 and 2. Cell culture; growth curve analysis; SDS-PAGE; Western blot analysis; PCR

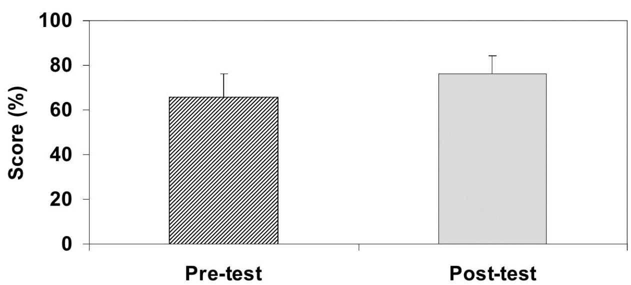
Vogelstein, Johns Hopkins Hospital, Baltimore). Both cell lines are easy to grow and maintain, and do not require specialized culture media. For the molecular biology component, students were taught protein extraction and quantification, SDS-PAGE, Western blotting, genomic DNA extraction and electrophoresis, plasmid extraction and electrophoresis, restriction enzyme digestion, and PCR (Table 1). For all molecular biology techniques, students were taught the principles behind a technique before using it in an experiment. For example, students learned how to perform PCR by carrying out a PCR control reaction, with a known outcome. They then carried out a PCR-based DNA fingerprinting exercise that required interpreting the experimental outcome. Students had hands-on experience with all techniques. We divided them into groups of three and each group performed every technique. They were given protocols the previous day to prepare and we discussed the procedures in detail before each group carried out the experiments.

In addition to the techniques we taught, students carried out collaborative tutorials on reading and writing scientific papers, looking up reference papers, and designing and carrying out experiments using case studies.

After completing the training components of the program, students participated in one of two research projects currently ongoing in our laboratory (Table 2). Students worked in pairs, with each group designing its own protocol, which was then presented to the class for discussion. Several protocols overlapped, so we paired complementary teams and divided the work so that each group conducted part of a more complicated student-designed experiment. All understood that data collected by each pair was critical to the overall success of the experiment.

In the final week of the program, we gave the students a previously-unseen protocol, a plasmid extraction kit. They had to perform the extraction without mentor guidance, as a means to assess their ability to integrate their learning on a new task.

Figure 2. Lawson's pre- and post-program test results. Students completed Lawson's Test of Scientific Reasoning at the beginning and end of the summer program. Questions in the test were grouped to analyze different aspects of scientific reasoning, as detailed in the text. Error bars indicate standard deviation.



Learning Assessment

We assessed our program in various ways. Students participated in the analyses voluntarily and anonymously. First, we gave students a pre- and post-program assessment of scientific reasoning. They completed Lawson's Test of Scientific Reasoning (Lawson, 1978), a multiple-choice test, on the first day of the program. The same test was then given five weeks later on the last day of the program. Lawson's test has 24 multiple-choice items, ranging in complexity. Each item involves a demonstration using some physical materials and/or apparatus. For each item, the student answers a question or predicts an outcome. To analyze our results, we grouped the questions into six groups of four related questions (G1 − G6). Group 1 involves the concepts of conservation of weight and displaced volume. Group 2 examines proportional reasoning. Group 3 looks at controlling variables. Group 4 examines combinatorial reasoning. Group 5 examines probability. Group 6 explores controlling variables and experimental design. The maximum number of points for each group was 4. A paired *t*-test was used to analyze the data.

Second, students performed a self-assessment, by means of an online questionnaire (Student Assessment of Learning Gains). The questions were rated on a Likert scale from 1 to 5 wherein "1" indicated the examined parameter was of no perceived help to the student, while "5" indicated that the examined parameter was very helpful. In a second component of the SALG, we examined whether the summer experience influenced students' ideas about their futures. These questions were also scored on a Likert scale.

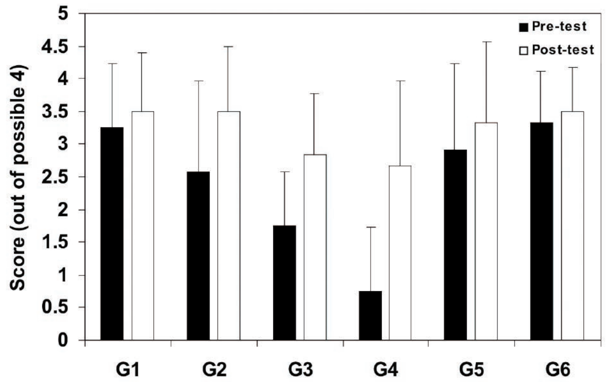
In addition to these formal assessments, we gave participants frequent worksheets and quizzes to assess their understanding of each technique.

Results & Discussion

In the pre-and post-program Lawson's test, we found that scores increased significantly from an average of 65.6% ± 10.8 for the initial test to 76.4% ± 7.8 ($P < 0.01$) for the second test, indicating the students increased their scientific reasoning as a result of the program.

When we analyzed each question group individually (G1-G6), we found that while students' scores did improve on all questions, in four of the question sets (G1, G2, G5 and G6) the increase was not significant (Figure 3). The questions in all four of these groups are logic-based, with some mathematical application. For example, G5 is a probability-based set of questions in which students are asked to predict a number of different shaped and/or colored wooden pieces pulled out of a bag.

Figure 3. Pre- and post-program test scores. Average student scores for questions in the pre-test (closed bars) and post-test (open bars) are presented in the question groups detailed in the text. The maximum score for each group of questions was 4. Error bars indicate standard deviation.



However, in both G3 and G4, students showed a significant improvement in pre-and post-program test scores (Figure 3). Average results for G3 increased from 1.75 ± 0.82 to 2.83± 0.94 ($P<0.01$), while those for G4 increased from 0.75 ± 0.97 to 2.67 ± 0.13 ($P<0.01$). This result was interesting to us. Both G3 and G4 include problems that require participants to examine different variables and experimental design: In G4 for example, students are presented with the problem of fruit flies position in a glass tube. The flies' position is affected by colored light and/or gravity. They are asked to determine which variable(s) affect(s) the flies' position. The significant improvement in the scores on these two question sets (controlling variables and combinatorial reasoning) indicated to us that students' general scientific reasoning had improved during the program. It is interesting to note however, that in both of these question sets, student scores were notably lower than in the other, less complicated question sets, even at the end of the program.

The results of the SALG were very positive. In all categories examined, students responded favorably to the questions (Table 3). Representative questions and responses are presented in Table 3.

One of the unanticipated responses from students was the extent to which they enjoyed working in groups and collaborating on the research projects. Many people who attend BMCC are part-time students. They attend a number of classes each semester, while juggling jobs and families. For this reason, they seldom get the opportunity to work closely with peers who share their academic drive and interest. Accordingly we think the emotional experience generated may have positive, long-term consequences.

Insights

The results of this project indicate that a summer molecular biology research program does benefit community college students. Initially we had concerns that the program was too extensive. However, participants were easily able to complete our basic curriculum, even though only a few of them had any prior experience with the techniques. Nevertheless, we found they all

Table 3. Representative responses to questions posed in SALG survey. Students were asked to rate their perceived learning gains on a scale of 1 (no help) to 5 (very helpful). Their responses were qualified with written comments, a representative sample of which are presented in this table.

REPRESENTATIVE QUESTIONS	REPRESENTATIVE RESPONSES
1. Did the program activities help your learning?	• *Overall, I have learnt* [sic] *a great deal in the last five weeks. From techniques and procedures that I never knew existed, to the familiar ones we refined, the hands on concept of the program really made the strong connection to the "real world" of research and its techniques.* • *I thought this class* (was) *an extreme learning opportunity. This is a way to learn procedures not normally learned.*
2. Did the quizzes and worksheets help?	• *I was very comfortable with being given assignments and quizzes because it helped reinforce what I learned in the program.* • *The quizzes were very helpful. It* [sic] *helped me retain the protocol*.
3. How well do you think you understand the techniques you were taught?	• *Each procedure was explained step by step, so we* (were) *not only able to understand how to carry out the activity but more so the scientific reasoning for each step of the procedure.* • *Being able to understand what I was doing and why was very important. Doing procedures from a paper doesn't help, but knowing WHY actually integrates the protocols even further.*
4. How much did the class improve your skills (in solving problems, designing experiments, finding trends in data, and critically reviewing articles)?	• *This class has taught me to think more analytically and view all possible sides of a situation before coming to a conclusion.* • *I have learned invaluable people skills, technical skills, scientific reasoning, practical knowledge, and a greater understanding of the world because of this* (program).
5. To what extent did this program improve your confidence in your ability to conduct research?	• *I thought I was in over my head at the beginning of this project but I learned that I am more than capable of being a scientist. I have gained skills and expertise in various faculties of thought that I will take with me for the rest of my career and my life. I have learned invaluable lessons about success and failure and how to deal with both. I never thought I would love science as much as I do now.*

mastered the basic techniques quickly. We realized early in the program that it was necessary to give the students handouts of the next day's protocols as this greatly decreased their anxiety and uncertainty about the sometimes-complicated procedures.

Using ready-made kits to teach techniques allowed us to cover more material as they provided an easy introduction to procedures. Use of the kits also significantly reduced time needed to organize and set up hands-on experiments. However, by themselves, kits are somewhat limiting since they are designed for simplicity and are thus somewhat abbreviated. We felt that kits alone would not teach students the details a research scientist would need to know; therefore, we either followed the kits with a research project or discussed the missing details in depth with the students.

We did find that while we were able to teach all the techniques we planned to in the training session, the amount of time available for actual research could be increased. Although the students did design and carry out tissue culture-based projects, they were only able to carry out the experiments once in the available time. We were fortunate that all the experiments went well. Had contamination of the cultures become a problem, the students would not have obtained data. In the future, we will increase the length of the program to six weeks, to allow additional time for the research component.

One of the most positive results came from the SALG assessment in which we asked students whether they were likely to continue in science (Figure 4). The majority of them expressed interest in graduate school and a scientific career and also felt more confident in themselves as academicians. We are pleased that six of the eight students remaining at BMCC (the other four graduated) plan to continue their research with us during the fall semester.

The National Science Foundation (2006) reported recently that the number of science and engineering degrees awarded to minorities is at the lowest level since 1993, a trend found throughout the country. As noted by Hoagland (2002), "...many students drop out of science courses because education at the undergraduate level too often treats science only as something to be memorized rather than something alive, personal, and full of creative potential. Too many students never see science education as relevant to them, and they leave school without the tools to understand much of the modern world." It is well documented that undergraduate research experiences enhance interest in Science, Technology, Engineering and Math (STEM) careers and improve retention of minority students in STEM fields (Nagda et al., 1998; Hathaway et al., 2002; Seymour et al., 2004). This summer program provided students with an opportunity to experience something not usually offered at a community college (and in our hands was a successful endeavor). In the words on one of our students, "I didn't have any opinions with science research in the beginning of the program. With all of the work and understanding what goes on behind lab doors, I can appreciate the work that is done. This program has gotten *[sic]* me to think about pursuing a career in research. I want to always be enlightened."

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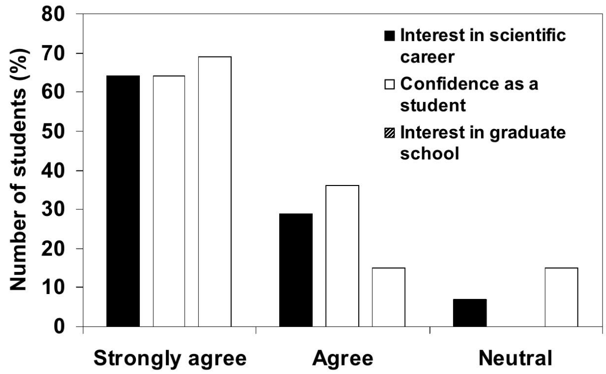
Figure 4. Student assessment of gains from the summer program.



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