CUR Quarterly
COUNCIL ON UNDERGRADUATE RESEARCH

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CUR Focus

Defining and Measuring Participation in Undergraduate Research at the University of Georgia

Many four-year colleges and universities are making solid progress in implementing the Boyer Commission (1998) recommendation to make "research-based learning a standard" in undergraduate education. However, the ways in which undergraduates are introduced to research and the methods by which we define and measure participation in undergraduate research (UR) vary widely. In our recent *CBE Life Sciences Education essay* (Fechheimer, Webber, and Kleiber 2011; http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3105922/pdf/156.pdf), we described the dramatic increase in undergraduate research activities over a 10-year period at the University of Georgia (UGA). In addition, we analyzed achievement scores of 2005 baccalaureate graduates at UGA and, based on that data, our results confirmed that students' participation in undergraduate research contributes to their academic success. Reports of increases in participation rates in undergraduate research, both at our institution and at many other four-year colleges and universities (Hu, Kuh and Gayles 2007), have been most gratifying. The interpretation of these findings concerning participation, however, is hindered by differences in the methods used to measure students' participation in research, and these differences impact the ability to make comparisons about participation both within and between institutions. Here we present our approach to defining participation in undergraduate research in the hope that it might help other researchers arrive at a consistent definition of such participation.

We chose to define engagement in UR operationally, based on a strict definition, which is a student's enrollment at any point during baccalaureate study in specific courses designed exclusively for the conduct of UR. Credit hours generated from enrollment in such courses at Georgia served as the source of data in our recent *CBE* essay (see Figure 1). Because each course was identified with a program of study, we were able to further identify the increase in UR credit hours produced in each discipline across the entire university, which we then grouped into credit hours earned in the sciences, social sciences, humanities, and arts. This method also allowed us to assess the number of semesters of UR engagement for students. In addition to counting student credit hours generated, we also identified the number of students who participated in official UR activities such as presenting a paper at the annual campus UR symposium or students who completed a senior thesis (see Table 1). This information was based on data compiled by our university's Center for Undergraduate Research Office (CURO).

Table 1. Selected Capstone Student Outcomes from Undergraduate Research at UGA

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Year	# Students Presenting at CURO Symposium	# Students Submitting Honors Thesis	CURO Scholar Distinction
1997		19	
1998		23	
1999		46	
2000	68	63	
2001	67	68	
2002	138	69	6
2003	138	106	9
2004	115	89	12
2005	159	90	16
2006	143	104	35
2007	191	108	35
2008	211	67	35
2009	197	69	35

There are both advantages and disadvantages to our method of identifying participation in UR. The disadvantage of the method is that students participating in UR as a volunteer, a paid worker, or as an enrolled participant in courses not included in our operational definition were not counted. Thus it could be argued that our results underestimate the extent of participation in UR. However, the use of institutional data has advantages in that they cross all disciplines, allow measurement of the duration of engagement in research, identify the completion of "capstone" activities, and are amenable to retrospective as well as prospective study. Further, this method does not suffer from the problems of accuracy and low response rates that plague student surveys.

In addition to examining engagement in UR-related activities, we also sought to investigate the effect of students' participation in UR on their cumulative grade point average (GPA). After obtaining approval from our university institu-

FIGURE 1. Student Credit Hours in Undergraduate Research Courses at UGA 1999-2008
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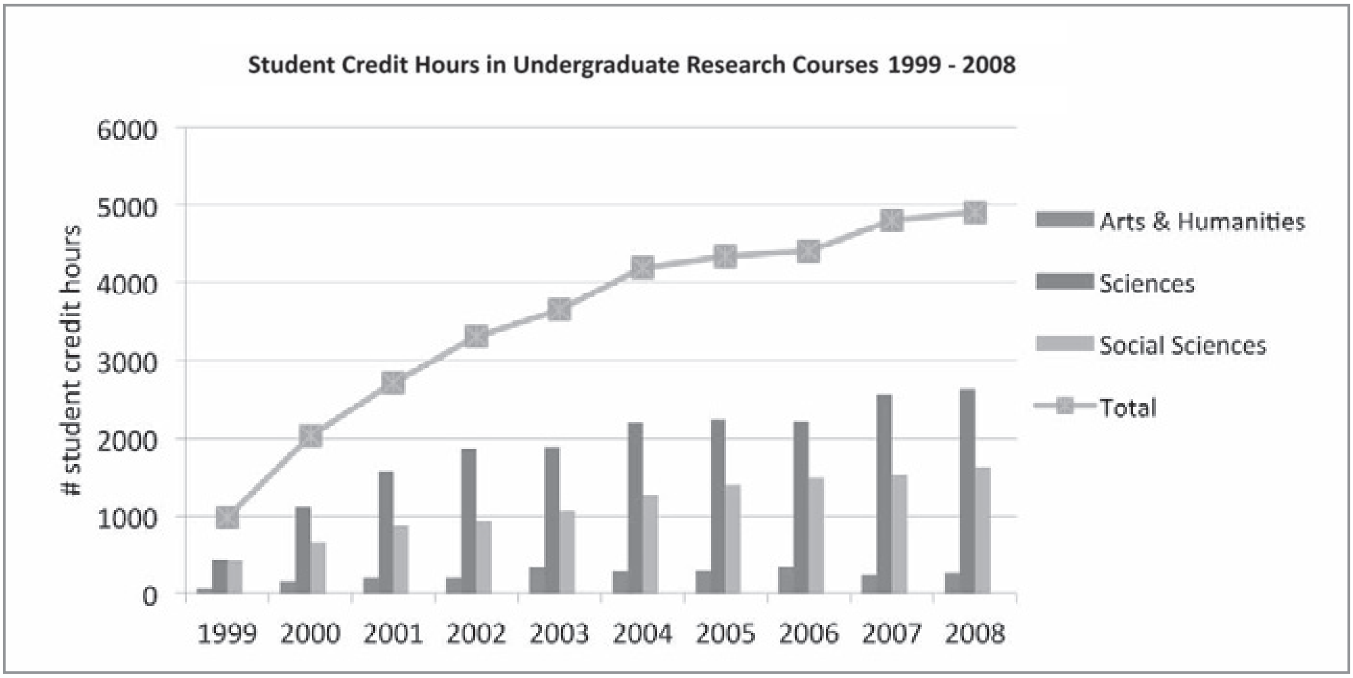

tional review board, we examined demographic and student ability data from the university's student records system on all students from one recent baccalaureate graduating class (approximately 5,000 students). We identified participation in UR by the graduates' previous enrollment in designated UR courses, as described above. This retrospective analysis enabled us to examine enrollment in UR courses over students baccalaureate careers, to use their SAT scores to account for differences in student ability, and to examine differences in cumulative grade point averages based on the number of UR courses in which they enrolled. Statistical analysis of these data supported a relationship between UR and student success and a clear positive effect of extended engagement in UR.

We agree with Beckman and Hensel (2009) and Berkes (2008) that UR participation rates in the published research vary depending on the method or source of data used to determine the participation. For example, data on UR participation can be collected from institutional databases, faculty reports based on the number of students who work in their labs or other research programs, student reports from satisfaction surveys, or UR program records that document the number of students enrolled in a formal UR or honors program. Institutional database records can be very helpful in identifying UR participation at the current time or prospectively over multiple semesters or years, and can be especially helpful if one wants to examine UR participation across majors or disciplines. An institutional database may include a "flag" or indicator of UR activity, and this can be measured by student and/or faculty member. In addition, databases can effectively identify student enrollment in UR courses, and, if desired and approved by the institution's IRB, can include other relevant information on each student. Student enrollment, when combined with demographic data such as ability scores, grades earned, majors, credit hours completed, and cumulative number of UR experiences completed, can yield important information on the impact of UR participation.

In summary, there are a number of ways to define undergraduate research and to measure participation in this important activity. In addition to counting involvement by just the number of student participants, it is important to consider factors related to the breadth, depth, and duration of the activity. Our use of university database records, in combination with information on undergraduate research programs, offers numerous advantages, allowing for comparisons over time, between disciplines, and across institutions.

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For the online version of CBE Life Sciences Education, visit: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3105922/pdf/156.pdf

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SPRING 2012 • Volume 32, Number 3

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A Quantitative Model for Predicting Which Features of Undergraduate Research Aid Acceptance into Graduate Education

Major efforts are under way to increase students' participation in undergraduate research, primarily in the STEM (science, technology, engineering, and mathematics) disciplines, but in other disciplines as well. However, we also are entering a period of decreased funding for higher education from state sources, governmental agencies, and perhaps even private sources. This financial scarcity will impede the development of research-rich environments for undergraduate students unless we produce a powerful way to justify the extra expense in money and faculty time allotted to support undergraduate research. Evidence in support of undergraduate research is certainly accumulating, but we need more rigorous proof of which elements constitute effective student participation. Thus we are proposing a quantitative model, logistic regression, that can predict the relative usefulness of various components of the undergraduate research experience and thus advance our thinking about such opportunities—shifting undergraduate research from its current status as a moral imperative into a proven centerpiece of effective undergraduate training (see Paul 2011).

In the 1970s, proponents of undergraduate research began publishing documentation showing its importance. These efforts and a dozen papers in the 1980s were followed by the supportive report of the Boyer Commission on Education (1998), the National Science Foundation's Integration of Research and Education grants, and private funding of undergraduates' research participation. Calls for evaluation of undergraduate research programs began about a decade ago (Manduca 1997; Spilich 1997), and subsequently more than 50 articles have been published espousing the effectiveness of students' participation in undergraduate research (see Table 1 in Junge *et al*. 2010). Most of this evidence has been case studies and anecdotal reviews of student and faculty experiences, citing improvements in student learning outcomes, critical thinking, and personal motivation. There have also been useful before-and-after surveys and even a few large-sample studies that pool data from multiple undergraduate research settings (Mabrouk and Peters 2000; Merkel 2003; Lopatto 2004, 2007; Seymour *et al*. 2004; Russell *et al*. 2007). However, the vast majority of these studies do not compare undergraduate research participants with non-participants, and most lack methodological rigor in their designs (Adhikari and Nolan 2002; Bauer and Bennett 2003; Junge *et al*. 2010).

What is at stake is the ability of colleges and universities to provide effective undergraduate education across a wide spectrum of disciplines. If, in fact, undergraduate research is an absolutely important aspect of the recruitment, development, and retention of students majoring in STEM and other disciplines and their matriculation into graduate programs and subsequent careers, then institutions of all kinds need to understand the parameters of that participation.

The difficulties associated with providing this research experience have been addressed several times by articles in *The Chronicle of Higher Education*, which have outlined the pitfalls of undergraduate research at predominantly undergraduate institutions (see Guterman 2007). In spite of such admonitions, there has been a steady march toward undergraduate research programs in many higher education institutions. For example, at our institutions, Brenau University and Gainesville State College, there are shifts toward the research university model. The lack of "professor-extenders," such as graduate students and laboratory technicians, at predominantly undergraduate institutions can create a paradox in which there is a decrease in faculty teaching and advising in exchange for a focus mentoring on fewer students in the undergraduate research program (Malachowski 2010). Indeed, this problem almost certainly extends to research universities as well.

The technical need, then, is for the development of effective evaluation procedures using a statistical model that can predict the importance of the multivariate nature of undergraduate research participation. Rather than being critical of the significant quantity of studies that have been undertaken thus far to validate undergraduate research as an effective pedagogy, we are proposing to expand the inquiry using a more complex statistical approach employing multiple variables, and then focusing on a few significant ones if they are found to exist. We have also realized from the existing large-sample studies that pool data from multiple undergraduate research settings that there is a need to develop a framework that can be used to define the undergraduate research situation in a given university environment—one that can also be used as a predictive model for individual undergraduates who seek admission to graduate education and subsequent careers.

The Logistic Model

The choice of a methodologically rigorous assessment model to analyze the effectiveness of the amount and type of undergraduate research experience needs to include (1) multiple categorical variables, (2) indicators of the relative importance of each of the categorical variables, and (3) probability of a particular outcome. We have chosen a statistical approach called a logistic regression, or a logistic model, because it can incorporate several predictive variables that may be either numerical (e.g., cumulative GPA) or categorical (e.g., whether the student wrote or co-authored a publication). Conventionally, the variable z is used to represent the impact of the set of independent variables. Thus z, known as the logit, is a measure of the contribution of all the independent variables used in the model, and $f(z)$ represents the probability of a particular outcome, running from 0 to 1.0. Our proposed logistic model is listed in Table 1.

Table 1. Proposed Logistic Regression Model

$$f(z) = e^z/(e^z + 1)$$

where $z = \beta_0 + \beta_1 R + \beta_2 I + \beta_3 S + \beta_4 G + \beta_5 C + \beta_6 M + \beta_7 P + \beta_8 A$, and

β_0 = regression intercept

$\beta_1, \beta_2, \beta_3\ldots$ = regression coefficients for the categorical variables

R = number of contact hours of primary research

I = number of contact hours of internship

S = number of contact hours of service learning

G = total number of contact hours of group or collaborative work

C = number of credit hours of STEM courses taken

M = number of professional meetings attended

P = number of student publications written and submitted

A = cumulative GPA

The proposed logistic model can demonstrate the relative importance of undergraduate research variables, as well as other predictors, in students' acceptance into a graduate degree program. Since this model is to be used in our study only for biology majors, we have selected acceptance into a graduate degree program as the predicted outcome variable of merit because nearly all careers in biological and biomedical fields require graduate training. We have adopted the analysis choices of Junge *et al*. (2010) and have included a number of graduate degree programs, including ones in life and natural sciences (MS, MA, PhD), health sciences (MPH, MSN, PsyD, MD, DMD, DPT, DNP, PharmD, DVM), and professional/trade/applied sciences (JD, MBA). In our model, the calculated $f(z)$ will be the predicted probability of being accepted into one of these degree programs.

Choice of Categorical Variables

The choice of categorical variables starts with three types of undergraduate research experiences: primary research (defined as designed, executed, and analyzed original research projects), internships (defined as a shadowing experience or as working in a lab on someone else's already-designed projects using their research methods), and community-service learning (defined as projects that have a research component but are actually more rote in nature, such as conducting a survey).

Subsequent analyses may tell us whether research experience helps steer students towards pursuit of a PhD, while service learning may be found to be more important for other graduate-level studies, such as pharmacy and public health. In each case, we will determine the number of total contact hours that students spent on their projects, whether they undertook the projects individually or in a group, whether they attended or gave a paper at a professional meeting, and whether they co-authored a paper. We will also collect data on other variables not a part of the present model. These will include gender, ethnicity, presence of a disability, ratings of research mentorship, involvement of peer mentorship, and scores on three standardized tests: the Educational Testing Service Field Test in Biology, the California Critical Thinking Skills Test (CCTST), and the California Measure of Mental Motivation (CM3).

We realize that there are a wide variety of variables and that it is impossible to include all of them. However, a logistic analysis that starts with a reasonable number, say eight, and that ultimately focuses on a small number of variables that prove to be statistically significant is an advantage. During this process, non-significant variables may be discarded and new combinations tested in an iterative process.

Data will be collected using a survey form filled out by biology majors at the end of their senior year. Data from each categorical variable will be analyzed by means of a commercially available logistic regression model using a personal computer. Beta coefficients will be determined, and categorical variables not contributing significantly to the predictability of the model will be removed from the proposed model's equation. Variables not included in the original equation will be included and analyzed in an iterative fashion, until a final equation is selected. Beta values in the final equation can be used for the predictions and analyses concerning the model's potential usefulness.

Simulated Run of the Model

Although collecting data for a complete analysis and validation of the model will take more time, we have undertaken a simulation to determine whether the logistic model is generally workable for our goals. To generate a sample data set, we used the graduating biology majors from Brenau University in 2010, about half of whom had undergraduate research experiences and half did not, and repeated the same data up to a simulated total sample size of 403. Running both a general regression model and a logistic model showed that GPA overpowered everything ($P < 0.001$) in its prediction of graduate school admission. This is consistent with what we know about the importance of GPA in this process.

We then ran combinations of variables in the logistic model by trial-and-error and found that in this simulated sample, two other variables made a statistically significant contribution: the number of primary research contact hours ($P < 0.001$) and the number of credit hours of STEM courses taken ($P < 0.001$). None of the other variables, such as meeting attendance and paper writing, seemed to be significant in this sample. This shows that the design of obtaining data for many different parameters that might be involved in winning entry to a graduate program, and then using an iterative process to winnow them down to a statistically significant smaller group, is indeed a useable methodology for pursuing questions about the relative importance of those parameters using the logistic model.

Anticipated Challenges

One of the liabilities of the logistic regression model is that it may overestimate the beta coefficients or the relative importance of the categorical variables at sample sizes less than about 500. As the sample size increases, the accuracy of the statistic likewise increases (Nemes *et al*. 2009). So a significant effort to attain the needed sample size must be undertaken. In order to initiate a study of this magnitude, we have undertaken a collaborative effort, which will proceed over two or three years, to obtain data from the 870 biology majors at three predominantly undergraduate institutions in Northeast Georgia: Brenau University, Gainesville State College, and North Georgia College and State University.

Another challenge is pre-selection of only “top” students by the faculty to participate in undergraduate research experiences, particularly if those venues are outside the university (externships). Such externships are precious and protected by the faculty members who oversee the undergraduate research program. This is a challenge because it introduces a bias into the number of students who have an opportunity to show a graduate admissions committee they had a chance to do research. A third challenge is that in any given college or university setting, the opportunities for undergraduates to conduct research are seldomly abundant. Their rarity almost dictates that only the best, most motivated students will apply for them and be granted participation. These two challenges may be addressed by specifically designing research opportunities in such a way that other students without the highest GPAs have a chance to participate in research. With proper attention to mentoring, such less-than-top students may pose minimal risk to the program. Of course, all students in a cohort of data (graduating class), both outstanding students and all others included in undergraduate research, must apply for graduate education for the analysis to be valid.

Another challenge we have noticed is that of obtaining an accurate record of the number of hours students actually spend on research. This is best met by requiring students to keep a log of their research hours, as well as requiring them to meet frequently with their mentors. At these meetings, mentors can verify the hours and research activities listed in the log, since these mentors are actively overseeing the research.

Potential Usefulness of the Logistic Model

The significance of our efforts is that ultimately we may be able to determine predictably which elements of an undergraduate research experience are the most pivotal and effective in aiding students to advance in their educational and professional careers. It will enhance the current state of undergraduate research by validating a new statistical tool to be used in assessing its impact.

The practical applications of our predictive model are potentially threefold. First, we should be able to determine the specific parameters of the undergraduate research experience that are important for undergraduate education, including the type of research (primary research, internship/shadowing, or service learning) involved and the number of contact hours of experience that have an effect. We will also be able to determine whether students’ experience is more valuable if undertaken as a group or individually. We can determine if undergraduate research participation causes students to take an increased number of courses in their own major and in related and supporting disciplines, as the paper by Junge *et al*. (2010) claims, and we can further test that finding. We also will be able to determine the relative importance of students’ giving a presentation at a professional conference or writing a research paper. And we can set up a logistic regression analysis to determine the importance of items thought already to be influential in graduate school admission: GPA, *Graduate Record Examination in Biology* scores, content knowledge, critical thinking, and motivation.

Second, the formula we finally develop will help an individual university plan for appropriate undergraduate research experiences for its students in order to maximize the effectiveness of limited manpower and financial resources.

Photo credit: Rudi Kiefer

Jessi Shrout, assistant professor at Brenau University, provides guidance as Rebecca Jones, sophomore undergraduate research student, works in the laminar flow hood on a tissue culture project involving the endangered fern species Asplenium heteroresiliens.

Such a scientifically validated model for the prediction of success in undergraduate students' education will support university administrators in their quest for funds to support undergraduate research in this time of constrained budgets in higher education.

Third, in the case of particular students, the final equation can help students determine what types of experiences they might need to focus on to improve their chances of winning admission to graduate or professional programs. A corollary of this calculation is that the predictive power of the logistic regression model might be used to determine which undergraduate research variables play an important role in the success of underrepresented groups (by gender, ethnicity, or disability status).

Conclusions

A quantitative model predicting the relative usefulness of various undergraduate research experiences can advance our understanding of and advocacy for undergraduate research experiences. Here we have argued in support of choosing a logistic regression model to undertake such quantitative assessment. Its advantage is that it produces a probability estimate of whether a particular combination of undergraduate research experiences (type of experience, GPA, etc.), will result in admission to a graduate education program. It also can incorporate both numerical and non-numerical data into its analysis. Its major disadvantage is that it requires a relatively large sample size, probably 400 students. Its greatest strength, though, is that it may be able to settle the issue of the importance of undergraduate research experience, and it may do this at a time when limitations are being placed on higher education—financially and in faculty time and resources. It is probable that only a powerful quantitative analysis such as this will allow supporters to argue successfully for continued and even expanded support for undergraduate research programs.

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