RUNNING HEAD: Web-based homework in college algebra

A comparison of web-based and paper and pencil homework on student performance in college algebra

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Abstract

College algebra fulfills general education requirements at many U.S. colleges. We assessed learning for 439 students in 19 college algebra classes at a large public university. Twelve classes used web-based homework called WeBWorK and seven had traditional paper and pencil homework. Analysis of covariance revealed no significant differences in algebra performance by homework group, ethnicity, or gender when statistically controlling for previous mathematics achievement. Results support the conjecture that WeBWorK is at least as effective as traditionally graded paper and pencil homework for students learning college algebra in lecture-based courses.

Keywords: evaluation of web-based homework systems, mathematics, pedagogical issues, post-secondary education, teaching/learning strategies.

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Introduction

Opportunities to learn at a distance through on-line courses and modules have grown rapidly in the last decade and internet-based enhancements to traditional courses have proliferated in science, mathematics, engineering, and technology (SMET) disciplines (WebNet, 2001; National Science Foundation, 1998). One internet-based accessory to SMET learning gaining popularity in the U.S. is web-based homework (WBH). To date, the most growth in, and research on, WBH systems has been in large lecture-based courses with more than 100 students (Dufresne, Mestre, Hart, & Rath, 2002; Gage, Pizer & Roth, 2001; Pascarella, 2002). In this study the focus was on smaller lecture-based college algebra classes of 30 to 40 students.

The importance of homework, especially for the advanced cognitive development expected in high school and college mathematics, has already been established by many individual and meta-analytic studies (Cooper, 1989; Cooper, Lindsay, Nye, & Greathouse, 1998; Keith & Cool, 1992; Warton, 2001). Ability, motivation towards mastery, quality of instruction, and amount of academic instructional time – including time spent on homework – are key factors in learning (Keith & Benson, 1992). However, it is clear from the research that homework is necessary, but not sufficient, for achievement on exams (Peters, Kethley, & Bullington, 2002; Porter & Riley, 1996). To examine the potential for shifting from traditional written homework assignments for skill-building to web-based homework, this study compared achievement gains,

measured by common exams, in college algebra skills between web-based (WBH) and paper and pencil homework (PPH) groups. The WBH tool used was WeBWorK.

Theoretical Framework

The educational perspective underpinning the development of WeBWorK and the instrument in this study is constructivist: understandings are conceptual structures built mentally by a learner. Such construction is generated by personal and social interaction with information, ideas, and processes. The "constructing" involves acquiring tacit and implicit knowledge of conventions (facts) in addition to the goal-based, cumulative, reflective, and self-regulated process of building operational awareness and structuring of conceptual understanding (von Glasersfeld, 2001; Vygotsky, 1978). Web-based homework may facilitate both factual and conceptual knowledge building for individual learners. However, we explicitly acknowledge that WBH is only a support tool for an individual's efforts to structure knowledge, and is by no means a replacement for dialogic interactions between teacher and student or the social generation of collective understanding of peer and near-peer group work. What WeBWorK does do is replace the unevenly implemented pedagogical interaction of homework grading with a uniform method of feedback.

Within the liberal arts tradition at U.S. colleges, the primary purpose of homework in college algebra is to foster development of a robust collection of algebra skills and concepts. The method for achieving this goal has traditionally been through separate practice with facts and concepts. Exercise sets in most college algebra textbooks offer drill practice with facts followed by practice with application and synthesis of concepts.

In many texts an exercise set ends with mildly non-routine problems aimed at generating disequlibrium and encouraging deeper reflection on concepts and their relationships. For a variety of reasons, from pressure to "cover" a proscribed collection of chapters in such textbooks to the personal epistemologies of students and instructors, the practice in college algebra teaching in the U.S. is to assign problems mostly from the first two categories (drill and application). Though there are efforts to rewrite college algebra textbooks along the lines of the reform of calculus in the U.S. (e.g., Kime, Clark, & Michael, 2005), this study was situated in a traditional setting and investigated perceptions of a web-based perturbation to that traditional setting.

Given the research on achievement differences related to ethnic, gender, and class status in the U.S. (Berry, 2003; Brown, 2005; Secada, 2000; Tate, 1997), one concern was that students from family cultures or socio-economic situations where computers were less common might be at a disadvantage if WBH were substituted for PPH. Similarly, educational research on student affective issues, particularly mathematics anxiety, suggested that attention be directed towards these concerns in designing, collecting, and analyzing data. Finally, the role of the instructor in achievement differences was an important consideration (Acherman-Chor, Aladro, & Gupta, 2003; Warton, 2001).

The results reported here are from the quantitative analysis of categorical variables: homework group, ethnicity, and gender. A phenomenological report on instructional style and student perceptions and reactions to the use of WBH has been published elsewhere (Authors, 2005). A limitation of the study was that no socio-economic classification data were collected, though the phenomenological study did investigate a proxy measure:

student access to and comfort with computers, the internet, and web-based interactions.

Research Questions

As pointed out by Cooper (1989), a thorough investigation of the relationship between homework and achievement should control for preparedness. In this quantitative-focused part of the investigation of the impact of the web-based homework interface WeBWorK on college algebra learning, the following questions were addressed:

(1) Did students in both the WBH and PPH groups have significantly different post-test and pre-test scores? That is, did the WBH and PPH groups learn college algebra in ways effectively measured by the instrument?

(2) When statistically controlling for pre-test scores, were there significant main effect differences in post-test scores depending on homework group (WBH or PPH), ethnicity, or gender?

(3) Were there any interaction effects between or among homework group, ethnicity, and gender on post-test scores?

WeBWorK

The WBH system called WeBWorK is an open-source, non-proprietary web-based interface developed at the University of Rochester (Gage, Pizer, & Roth, 2001). It uses problem libraries to create similar but individualized problems for each student. The libraries, written in PERL, can include calls to GIF and PNG illustrations, animated GIF's, HTML hyperlinks, JavaScript code and Java applets. WeBWorK has the potential to provide individualized graphical questions and interactive mathematical experiments for students to manipulate. Moreover, course management capabilities of the program

include: (a) detailed statistical information on individual student and whole-class progress, (b) adjustable due dates for individuals and groups, (c) group email lists for a class, and (d) exporting of grade data to spreadsheet programs. In the semester of this study, Fall 2002, instructors incorporating WeBWorK into their courses rarely used capabilities (a)-(c) but did make use of grade exporting.

The goal of WeBWorK is immediate "correct" or "incorrect" feedback. The WeBWorK interface does not correct a student's errors or give hints. WeBWorK simply lets them know whether or not they have submitted a correct answer. WeBWorK also allows users to choose to try again on the same or a slightly different problem. For this study, the re-try attempt was on a variant of the original problem. On the WebWorK pages students are encouraged to seek help from a fellow student, a tutor, or the instructor. They can do this in person or by email (there is a feedback button to generate email built into the WebWorK interface – see Figure 1).

Certainly, it would be possible to program into WeBWorK the capacity to give hints based on the type of wrong answer. However, for the college algebra classes discussed here, the question of interest was whether or not the simple "correct"/"incorrect" feedback and retry option were sufficient to achieve the goal of reducing instructor homework grading load while still encouraging student homework efforts and maintaining course achievement.

To use the WBH interface, students signed on to the WeBWorK server from any internet-connected computer. Students could download and print out the full assignment problem set. Once their work was complete, students entered their solutions into WeBWorK through a text window using standard computer algebra software syntax (see

Figure 1). After the due date, students could go back and review their submitted homework and view correct answers. Students could also re-work old assignments as a form of review for exams.

[Figure 1]

Methods

Every semester the college algebra course at the site of the study enrolls between 500 and 800 students in moderately sized class sections of fewer than 40 students each. An additional 200 to 300 students enroll in large lecture sections of 100 or more students each (not included in this study). The moderately sized class sections are taught by lecturers with advanced degrees (Ph.D. or Master's) or by Graduate Teaching Assistants who are working towards master's degrees in mathematics.

Data gathered

The primary data forming the basis of this report were pre- and post-test scores, demographic information, and course completion information. Additional information about homework policies and grades was also collected from instructors. All data for this study were from the moderate enrollment college algebra classes at the institution in Fall 2002.

A 25-item multiple-choice paper and pencil test over college algebra content was administered in the first and last weeks of the term in all moderate enrollment web-based homework (WBH) and paper and pencil homework (PPH) class sections. The same test

was used both times. Students recorded their choices on scanable answer sheets. The course coordinator for college algebra and the WeBWorK implementation supervisor developed the test. A panel of five expert college mathematics instructors established its face and content validity and the test was piloted in Fall 2001 before being used for the study. The exam covered the four main college algebra concepts: linear operations, slope, function notation, and operations with functions. Cronbach's alpha measures of internal reliability for the pre-test and post-test were .70 and .79 respectively. See Appendix 1 for the test.

Procedure

The college algebra problem library programmed into WeBWorK for the study was made up of exercises selected from the textbook used by all sections of the course (Stewart, Redlin, & Watson, 2000; permission obtained from the authors). Advanced WeBWorK functionalities (e.g., animations, multiple graphs) were not programmed into the problem library. Instead, items directly from the textbook were the basis of both WBH and PPH assignments. The college algebra course coordinator determined a list of suggested homework exercises, organized by textbook section, and provided it to the PPH and WBH instructors and to the WeBWorK programming team.

Each WBH and PPH instructor used at least 80% of these problems in assignments that were due weekly on a day and at a time determined individually by each instructor. PPH instructors reported that students completed the majority of homework outside of class time with approximately 65% of students completing homework regularly. Students in WBH courses completed their WeBWorK outside of class on a home computer or at

one of over 500 computers available on-campus in labs and in the library. According to the WeBWorK audit-trail, 78% of students regularly did their WeBWorK assignments.

Analysis

To answer the research questions, data analyses were conducted using a common statistical software package. A paired *t*-test was conducted for each homework group (WBH and PPH) and for the combined sample to answer the first research question about whether the test indicated college algebra learning had occurred. The hypothesis was that the students in each group (WBH and PPH) would have significantly higher scores on the post-test compared to their pre-test scores. A three-way Analysis of Covariance (ANCOVA) was conducted to answer the second research question about differential learning gains between WBH and PPH groups when controlling for a variety of demographic variables. Several null hypotheses were made for this analysis related to the three research questions. For each of the null hypotheses listed, there was research-based support. For H_1 and H_{2a} the driving reason was Cooper's (1989) call for ensuring relative comparability of treatment and control groups. Concern about the influence of societal factors – particularly ethnicity and gender – prompted the choice and wording of hypotheses H_{2b}, H_{2c}, and H_3 (Secada, 2000).

H_1: The WBH and PPH groups, separately and collectively, had no statistically significant score gains from pre- to post-test.

H_{2a}: Statistically controlling for pre-test scores, student achievement as measured by post-test scores was no different for WBH and PPH groups.

H_{2b}: Statistically controlling for pre-test scores, there were no statistically significant

differences in achievement among students of different ethnicities.

H_{2c}: Statistically controlling for pre-test scores, there were no statistically significant differences in achievement between students of different genders.

H_3: Statistically controlling for pre-test scores, there were no significant interactions among homework group, ethnicity, and/or gender.

Student Participants

The sample of students is representative of the large public university from which it was drawn and is an indicator of the increased diversity of students at all U.S. post-secondary schools. The light bars in Figure 2 indicate the distribution of students in the study by U.S. government ethnic identification. For comparison, the dark bars give U.S. national enrollment percentages (National Center for Education Statistics, 2000). Though the student population of the study was more diverse than the national average, its distribution was representative of the projected U. S. post-secondary demographics for 2060 (Delpit, 1996).

In Fall 2002, 644 students enrolled in the 19 moderately sized college algebra sections. Of these, 532 (84%) completed the course while 112 (16%) dropped or withdrew. Of the 532 who finished the course, 378 passed it with A (19%), B (28%), or C (24%). Another 59 students (11%) had D grades. That is, of the 644 who originally enrolled, 378 had a grade of C or better, a 59% pass-rate. Though slightly higher than the national average pass-rate in college algebra of 57%, this pass-rate was typical of the institution (Mathematical Association of America, 2004). Due to late additions, absences, and drops, complete data were available for a sample of 439 students, 83% of those who

finished the course. By homework group, students' scores were available for 302 (84%) of the WBH and 137 (81%) of the PPH students who completed the course. Although the sample contained more women (72%) than men (28%), this may be attributed to the institution's entering class average of 70% women and 30% men.

Instructor Participants

Assignments among the 19 moderately sized sections of college algebra - taught by 15 different instructors - were initially random with ten WBH and nine PPH classes. However, within the first two weeks of the term two instructors who had used WBH the previous term asked to be switched to WBH. Each of the three instructors who taught multiple sections of the course in Fall 2002 had at least one PPH section and one WBH section (see Table 1). In the end, 12 WBH sections were taught by 11 instructors and seven PPH sections were taught by seven instructors.

Four of the 15 college algebra instructors in Fall 2002 were master's graduate teaching assistants (1 man, 3 women) and had little to no college teaching experience. Nine were instructors with master's degrees who already had some experience teaching college algebra (7 men, 2 women), and two were male Ph.D. lecturers in mathematics, each with at least four years experience teaching college algebra.

Results

Before the primary analyses were conducted to answer the research questions, considerations were made regarding the attrition between the two homework groups. For Fall 2002 of the 532 students completing the course, data were available for 302 (84%) of the WBH and 137 (81%) of the PPH students. Though the drop-rate in the WBH courses

(13%) was slightly lower than in the PPH courses (18%), the difference of proportions was not statistically significant ($z = -0.39$, $p = .348$).

Paired t-Test Results

Paired *t*-tests were conducted to answer the first research question regarding the increase in student achievement after instruction in college algebra. Analysis consisted of the paired *t*-tests for the WBH and PPH groups as well as the combined sample, the results are presented in Table 2. There were significant differences between pre-test and post-test scores for each analysis: $t(302) = 17.41$, $p < .0005$ for the WBH group, $t(137) = 11.86$, $p < .0005$ for the PPH group, and $t(439) = 21.09$, $p < .0005$ for the combined group. Therefore, H_1 was rejected. That is, each group scored significantly higher on the post-test than on the pre-test. These results indicate that achievement in college algebra was significantly higher after the course than as students entered the course, which was expected.

ANCOVA Results

Three-way ANCOVAs were conducted to answer the second research question regarding differences in student achievement based on demographic information. The variables in the analyses were: the three independent variables: (a) homework group (PPH or WBH), (b) ethnicity, and (c) gender; the covariate (pre-test scores), and the dependent variable (post-test scores).

The results of the three-way ANOVA are presented in Table 3. The statistically significant result for the pre-test, $F(1, 415) = 70.92$, $p < .0005$, indicates that the pre-test is a viable covariate of the post-test in the analysis. However, there were no significant main effect differences on post-test scores after statistically controlling for pre-test scores

for homework group, ethnicity, and gender. Thus, analysis resulted in failing to reject H_{2a}, H_{2b}, and H_{2c}. It should be noted, for H_{2b}, results approached significance ($p < .10$). For the most part this was due to a large mean difference between students identified in school records as belonging to Asian ethnicity categories (e.g., Chinese, Japanese, Korean, Hawaiian, Filipino, Somoan, Vietnamese) and those identified as Latino (e.g., Chilean, Mexican, Puerto Rican).

There were no significant interactions between the three independent variables on post-test scores when controlling for pre-test scores, see Table 3. Consequently, we failed to reject H_3, These results indicate that achievement in college algebra was statistically significantly higher post-course than pre-course, regardless of demographic or homework group variables.

Discussion

Influence of WeBWorK in College Algebra Learning

The main result of the study in comparing post-test achievement between WBH and PPH groups was that there was no significant difference in performance. The two homework groups began in essentially the same place with no significant differences in scores between PPH and WBH students on the pre-test, and ended, as groups, about the same. As a result WBH appears to be at least as effective for educating students in moderately sized lecture-based sections of college algebra. One benefit of the WBH system may be that WBH saves instructor grading time while supporting student achievement at least as well as PPH.

It is important to point out that no statistically significant interaction of ethnicity by group or gender by group was found, indicating that any ethnicity- or gender-correlated differences in performance were independent of the student's being in WBH or PPH groups. That is, it seems that whatever may be culturally biased in the structure or processes of college algebra, the use of WBH does not appear to significantly exacerbate or diminish it.

Benefits and limits of WeBWorK

Unlike internet auto-tutorials, discovery learning modules, or electronic communication by instructors about individually graded homework (Hall, et al., 2001; Monson & Judd, 2001; Pascarella, 2002; Yazon, Mayer-Smith, & Redfield, 2002), the web-based homework of WeBWorK investigated here does not openly conflict with traditional direct instruction or lecture methods of classroom teaching nor does it take a large amount of instructor time. This is both good and bad.

The simplicity of WeBWorK is good in that the likelihood of its adoption by traditional college instructors is increased. This is particularly so if it is seen as a tool to eliminate the grading of large numbers of undergraduate mathematics homework papers. It may be bad, however, in that WeBWorK does nothing explicitly to challenge the notion widely held by many undergraduates and instructors that learning, particularly in college algebra, is a matter of habituation in skill practice rather than construction of personal knowledge structures rich in conceptual connections to previous learning (Laurillard, 1995; Kirschner, 2002).

It is clear from work to date on human-computer interactions that computers have a mediating effect on learning, particularly in mathematics, different from that of other learning environments (Karasavvidis, Pieters & Plomp, 2003; Liaw, 2002). What is also clear from the results presented here is that substituting WeBWorK for paper and pencil homework in lecture-based college algebra instruction does not appear to hinder student performance (as measured by the common paper and pencil tests). While it would be beneficial if WBH actually improved student performance, an interface as straightforward as WeBWorK is unlikely to lead to such a result. Nonetheless, WeBWorK may be used by college instructors to make their grading load more manageable and it appears to be at least as effective as PPH homework for most students.

One shortcoming of WBH is that though student and teacher can know quantitatively how the student is doing from their WeBWorK score, there is no qualitative information for the teacher to use in helping a student construct conceptual understanding. WeBWorK does not have a qualitative feedback mechanism (it just is not designed that way) that gets at what other evaluation methods can.

Learner-centered use of instructor grading time

While it is true that computer-based learning environments can act as catalysts for change in the perceptions students have of themselves as learners, such change is by no means automatic or persistent after a single semester course (Pascarella, 2002; Yazon et al., 2002). The benefit of delegating the masses of skill practice for which PPH is viewed useful to a web-based interface is that it allows instructors the flexibility to spend what would have been homework grading time on alternative forms of feedback that may be

more beneficial to students.

An instructor can choose additional formative and summative assessments to support the growth of students' intellectual autonomy in learning mathematics. If understanding is constructed by learners, then such construction can be facilitated through interaction and co-evolution of *both* the skill-practice available through an interface like WeBWorK and through assignments that help students build rich conceptual scaffolding to give context to their skills (Rittle-Johnson, Siegler, & Alibali, 2001). Some possible alternative methods for instructional interaction with students reported in the literature are projects (Gold, 2004), concept-based quizzes (Romagnano, 2001), and writing exercises (Bolte, 1999; Sterrett, 1992).

Future work

Several areas of research around WBH implementation hold great promise. First and foremost, replications of the study reported here are necessary. Additionally, qualitative exploration of student and instructor views in the context of WBH is needed. The authors have made a first step in this direction (Authors, 2005). As with any curricular innovation, it is important to discover how the intended curriculum is implemented, received, and activated for students. That is, what happens in classroom and other instructional interactions as the innovation is used? How is student engagement affected? Is student learning, performance, or persistence in mathematics modified? How? Investigation of these questions at other levels (e.g., secondary school) would also be valuable since web-based technology is likely to become ubiquitous in the schools.

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Table 2

Paired t-Test Results for Differences between Pretest and Posttest Scores for WBH, PPH, and Combined Groups in Fall 2002

		Pretest		Posttest		
Group	*N*	*M*	*SD*	*M*	*SD*	*t*
WBH	302	10.59	4.03	15.23	4.30	17.41*
PPH	137	9.50	3.11	14.16	5.08	11.86*
Combined	439	10.25	3.80	14.90	4.43	21.09*

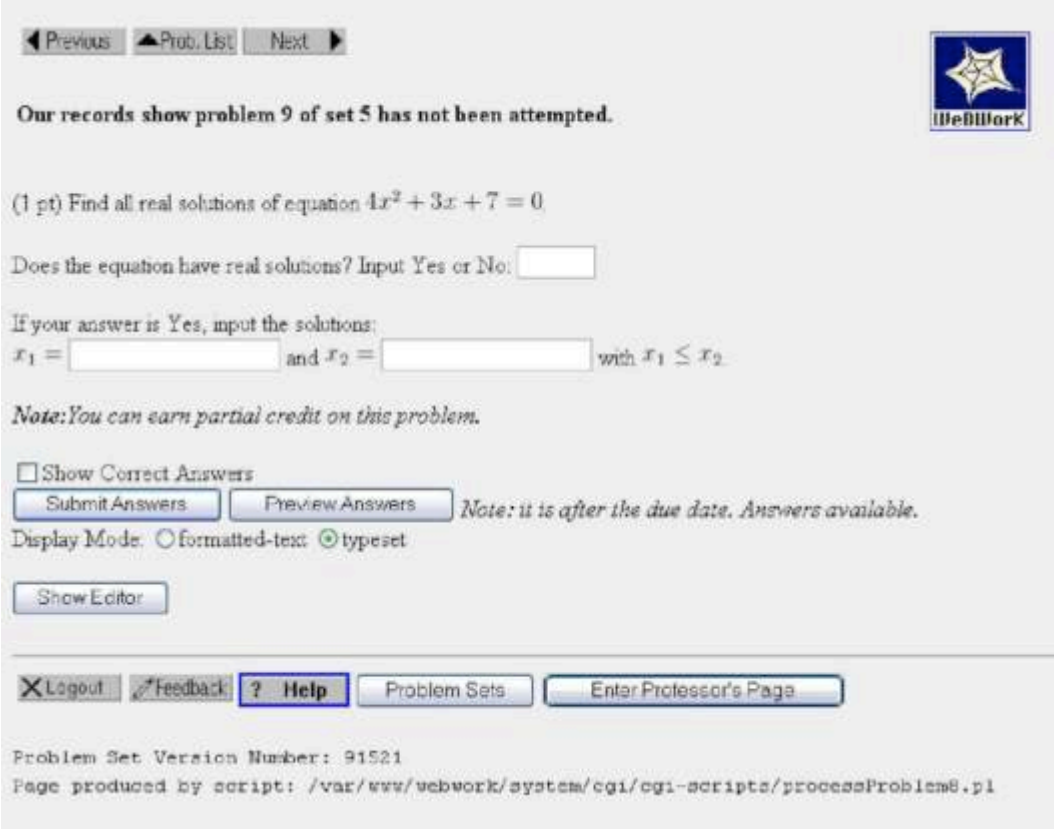
* $p < .0005$

Table 3

Three-way ANCOVA Results of Posttest Scores by Group, Ethnicity, and Gender Statistically Controlling for Pretest Scores in Fall 2002

Source	*SS*	*df*	*MS*	*F*	*p*
Pretest	1178.47	1	1178.47	70.92	.000
Group	38.12	1	38.12	2.29	.131
Ethnicity	163.78	5	32.76	1.97	.082
Gender	8.05	1	8.05	0.48	.487
Group Ethnicity	105.29	5	21.06	1.27	.277
Group Gender	0.35	1	0.35	0.02	.885
Ethnicity Gender	47.48	5	9.50	0.57	.722
Group Ethnicity Gender	23.15	5	5.79	0.35	.845
Error	6896.35	415	16.62		

Figure 1. Screen shot of a WeBWorK problem on quadratic equations requiring mathematical notation in the answer.



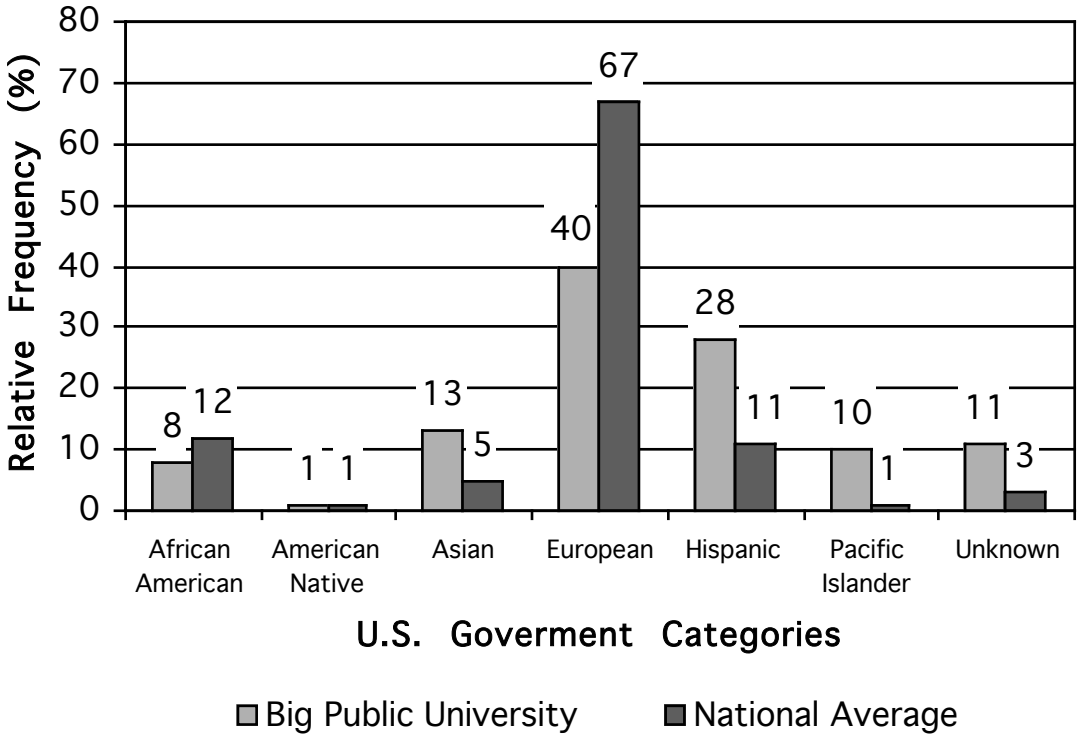


Figure 2. Percentage of enrollments, by U.S. government assigned demographic groups.