Supervised Study: Required Independent Research at a Community College Supports Persistence in Science

Anne B. Allison, Virginia V. York, Donna M. Hoefner, Melinda E. Clark, Marlena C. Yost, and Joanna R. Vondrasek*
Biology Department, Division of Health & Life Sciences, Piedmont Virginia Community College, Charlottesville, VA 22902

ABSTRACT

This study assesses the impacts of the Science program at Piedmont Virginia Community College and its flagship capstone research experience, Supervised Study, through psychosocial perceptions associated with persistence in science and through a comparative analysis of subsequent science bachelor's degree attainment. Supervised Study involves authentic, independent projects, a research methods course and learning community, and one-on-one faculty mentoring. The Persistence in the Sciences survey was used as a repeated-measures instrument in four semesters of Supervised Study. Positive trends were observed for self-efficacy, science identity, community values, and networking, while responses related to project ownership were mixed (n = 13). To contextualize these observations, transfer and bachelor's degree completion rates were analyzed. Students who earn an associate's degree in Science (n = 113 between 2012 and 2019) complete bachelor's degrees at high rates (66.4%). Moreover, they are two to four times more likely to major in physical and natural sciences than their science-oriented peers, who take many of the same courses, with the exception of Supervised Study. Notably, these comparison rates remain consistent between different demographic groups. These findings further describe a model for research at the community college level that supports persistence in undergraduate science for a broad group of students.

INTRODUCTION

Early independent research at community colleges is feasible without faculty research programs, partnerships, external funding, or even a large investment in facilities. Mandating independent research as part of the curriculum is an essential component of successful implementation. Requiring degree seekers to complete a structured capstone course with embedded, independent, mentored research enables financial aid, draws more underrepresented students into science, and provides a pathway to the institutionalization of undergraduate research. Such programs at community colleges remain rare but have the potential to transform science, technology, engineering, and mathematics (STEM) education by radically increasing the number and type of students who are exposed to authentic research early in their educations. This study describes such a model while examining psychosocial measures of persistence in science and tracking community college students after transfer and through completion of science bachelor's degrees.

Undergraduate research can take many forms and can be strengthened by faculty mentorship. Strong faculty mentorship is correlated with successful science identity and persistence, especially for students from historically underrepresented groups (Payton, 2004; Lundy-Wagner *et al.*, 2013; Linn *et al.*, 2015; Vandermaas-Peeler *et al.*, 2018). Given the well-documented benefits of early research experiences (National Research Council [NRC], 2003; Thiry *et al.*, 2012; Bhattacharyya and Chan, 2021; Frederick *et al.*, 2021), independent, mentored research during the first 2 years of

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*Address correspondence to: Joanna R. Vondrasek (science@pvcc.edu, jvondrasek@pvcc.edu).

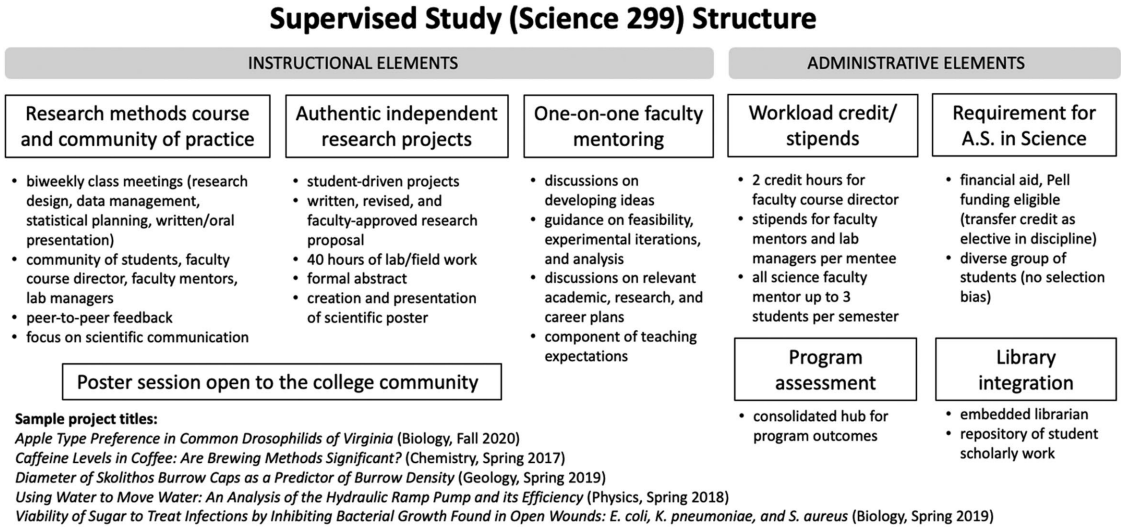

FIGURE 1. Structure of the Supervised Study (Science 299) research course and experience. Supervised Study includes multiple instructional and administrative elements that support students through an independent, authentic research experience.

college is a high-impact practice that could be more broadly instituted (Fletcher and Carter, 2010). There are examples of mentored independent research occurring within community college settings, such as programs associated with the Community College Undergraduate Research Initiative (www.ccuri.us) or the City University of New York (CUNY) Research Scholarship Program, an opt-in faculty-mentored research experience in the STEM fields, in which students are paid a stipend to participate (Nerio *et al*., 2019). While the CUNY program and others like it benefit participants, opt-in programs or programs based on faculty recommendation can produce a selection bias against students who are unable to pursue such experiences, whether because of time or financial constraints, lack of confidence, or lack of knowledge of how to seek out research opportunities (Awong-Taylor *et al.*, 2016).

Because undergraduate research at community colleges can have varied definitions, the model described in this study falls in the category of "conducting basic research at the community college" outlined by Cejeda and Hensel (2009). In 2010, a capstone research course entitled Supervised Study (Science 299) was implemented at Piedmont Virginia Community College (PVCC) in response to national calls to increase undergraduate research experiences in the life sciences (NRC, 2003; Cejda and Hensel, 2009; American Association for the Advancement of Science, 2011) and to provide a common academic experience for assessing student learning outcomes for the AS in Physical and Natural Science, a transfer-oriented degree. As shown in Figure 1, the structure of Supervised Study combines elements meaningful to student success in science education: a learning community of faculty and students and independent, mentored, authentic research. The required nature of the course ensures that all students graduating with the AS in Physical and Natural Science degree participate in undergraduate research, eliminating bias associated with opt-in or selective programs.

The Supervised Study experience is anchored by a one-semester, two-credit course that consists of regular class meetings. These meetings provide instruction on research design, experimental iteration, analysis, interpretation, and communication. They also stimulate peer feedback and provide a venue for communicating about science. The result is a close-knit learning community, similar to a community of practice, where students learn to share, listen, and seek support from one another and from faculty and laboratory staff (Thiry *et al*., 2011; Gardner *et al.*, 2015; Keiler *et al.*, 2017). In addition to the course element of Supervised Study, each student independently designs and conducts an authentic research project with guidance from a faculty mentor. Matched faculty mentors work one-on-one with each of their mentees (up to three) to help them develop ideas and identify the most relevant literature. Mentors and mentees also discuss feasibility, experimental design, data management, data analysis, and interpretation. The semester culminates with a celebratory luncheon and a poster session that is open to the college community.

Supervised Study research projects span a wide range of questions, but they have several common features: the answers are not known, the cost of the project is low (typically less than $100), and the experimental phase can be completed in 8 to 10 weeks. Although students can propose and conduct projects using novel systems and methods, they may also ask questions that build on model systems and methodologies they have used in prior course work, which includes multiple course-based research experiences. This practical framework increases the sustainability of the Supervised Study course by leveraging existing physical infrastructure and faculty and laboratory staff expertise.

Supervised Study was created with program assessment in mind. As described in the Science program's mission statement, the goal of the degree plan is to educate future scientists.

> The A.S. of Physical and Natural Science Degree promotes the spirit, history, and methodology of scientific inquiry. Through instruction and laboratory experience in biology, chemistry, physics, geology, students develop and demonstrate the ability to hypothesize, collect data, process data, and apply results to real-world problems. Graduates of the program are prepared to transfer to a four-year institution and continue science studies toward completion of a bachelor's degree.

Supervised Study, in addition to representing a student's successful path through the first two or three semesters of science course work, is designed to accomplish these goals, and it provides a simple structure for measuring learning outcomes of the Science program. Measures such as "students will be able to apply the principles of scientific inquiry in research" are embedded in Supervised Study, and the percentage of students achieving a certain benchmark on the research component score of the Supervised Study grade is analyzed for assessment and accreditation purposes.

This study examines factors not easily captured in institutional assessment, namely whether the Supervised Study capstone course influences student psychosocial outcomes associated with persistence in science. To address this question, the Persistence in the Sciences (PITS) survey (Hanauer *et al.*, 2016) was administered at the beginning and end of the semester in four semesters between 2018 and 2020. To complement this investigation, transfer and bachelor's completion rates were analyzed as objective measures of persistence. Here, Science students were compared with their nearest peers: a science-oriented subset of students from two additional PVCC transfer-focused associate degree programs, Liberal Arts and General Studies. Students in these other degree programs were identified as "science oriented" if they had completed the introductory course sequence in biology and/or chemistry, representing the closest comparison groups to Science students. Importantly, both Science and science-oriented students follow a similar common curriculum (Supplemental Material, Appendix 1), but only Science students are eligible for and required to take Supervised Study. Together, the psychosocial indicators of persistence and the undergraduate academic pathways that PVCC Science students follow help describe and contextualize a model for a required, faculty-mentored research experience at a community college that has proved sustainable for over a decade.

METHODS

Course Description

Supervised Study (Science 299) is listed in the PVCC course catalogue as discipline-specific sections: BIO 299, CHM 299, GOL 299, PHY 299, representing Biology, Chemistry, Geology, and Physics respectively (PVCC Catalog, 2020–2021, http://catalogue.pvcc.edu). The prerequisites for Supervised Study vary slightly by discipline, but all disciplines require instructor permission and typically include successful completion of two semesters of introductory science courses in the discipline. The course meets most Fridays for an hour and is coordinated by two full-time science faculty. Each year, a faculty member rotates into this role as an assistant director and then progresses the following year to the course director position, serving as the official instructor of record and receiving 2 hours of workload credit per semester. These course directors foster a learning community and provide feedback to students. The directors facilitate discussions about research methods, guide proposal writing, and provide instruction on statistical analysis. They monitor student progression and serve as liaisons between course stakeholders, including faculty, students, staff, and administrators. Course directors carry out event planning for the end-of-the-semester luncheon and poster presentation. Students' written project proposals must be approved by their faculty mentors before the experimental phase can begin. Over 8–10 weeks, students carry out approximately 40 hours of research in the lab/field. Toward the end of the semester, students write and revise a formal abstract, and they draft, practice presenting, and revise a scientific poster. Finally, students present their research at a poster session, and the Supervised Study community shares a celebratory lunch. All full-time faculty members mentor up to three students per semester. Two full-time lab managers and one part-time lab manager assist with research logistics and provide supervision to students working in labs and oversight for students carrying out field projects. Faculty mentors and lab managers receive modest stipends on a per-student basis, factored on tuition credit rates. A research librarian is embedded in the course to assist students with accessing literature and to help them develop scholarly skills. Library staff work to build and maintain a digital, searchable repository of student work. Eight out of eight student learning outcomes used for program assessment are measured in Supervised Study (Supplemental Material, Appendix 2). When external funding is available, some supply and poster printing costs are covered. Additional details about the administrative structure of the course and course materials are available (Vondrasek, 2018; Allison *et al.*, 2021; Supplemental Material, Appendix 3).

PITS Survey

This study was approved by Dr. Jolene Hamm, director of the Office of Institutional Research, Planning, and Institutional Effectiveness at PVCC (2014–2021). Researchers (A.B.A., V.V.Y., J.R.V.) handling sensitive data successfully completed the CITI Social-Behavioral-Educational (SBE) Foundations course (https://about.citiprogram.org/en/course/social-behavioral-educational-sbe-foundations).

The PITS survey instrument, as developed and validated by Hanauer *et al.* (2016), was administered at the beginning and end of four semesters in a repeated-measures approach. Participants for the survey were recruited from the Fall 2018, Spring 2019, Fall 2019, and Spring 2020 Science 299 courses at PVCC. Students volunteered to complete the survey twice. The pre survey was conducted during the second week of the semester, after the first introductory meeting of the course, but before project proposals were due. The post survey was conducted after the poster presentations but before the end of the semester grade deadline for faculty (roughly a 10-day window).

The PITS survey employs a Likert scale, wherein lower Likert numbers represent lower levels of agreement with the question. We assessed all six factors of the original PITS survey: Project Ownership–Content, Project Ownership–Emotion, Self-Efficacy, Science identity, Scientific Community Values, and Networking. As part of this survey, students were also asked to provide demographic information, including years since high school graduation, age, race/ethnicity, and gender, as well as institutional student identification numbers to track survey responses. Informed consent was provided by discussing the survey with students verbally and in writing, and students consented to the collection of data for research purposes by clicking on the survey link. The survey was voluntary, bore no weight for students' grades, and was not linked to the learning management system. To assess internal consistency, a Cronbach's alpha was calculated for each factor and the survey as a whole. For the paired

survey data, Pearson's correlation coefficients were calculated for the mean differences for each factor.

Institutional Data

Graduation, transfer, and demographic data were obtained from the Virginia Community College System's (VCCS) Central Office in Richmond, VA. Data for students enrolled between Summer 2012 and Spring 2021 in the AS in Science, AA in Liberal Arts, and AS in General Studies programs were compiled. The Liberal Arts and General Studies programs at the college are, like the Science degree, transfer-oriented degrees. Other transfer degrees offered by the college (Business Administration, Computer Science, Education, Engineering, Music, and Theater and Drama) were excluded, as they were unlikely to yield many students intending to transfer as natural or physical science majors. Historically, the Liberal Arts degree has been the degree of choice for students intending to transfer to the University of Virginia (UVA), the flagship state university located a few miles away from PVCC, regardless of intended major, as its course work aligns with UVA's transfer requirements. However, since the revisions of the PVCC Science program in 2012, which allowed curricular space for 2 years of a foreign language, the Science program now aligns with UVA's requirements. Despite this alignment, there is residual preference for the Liberal Arts degree among some students and advisors.

Liberal Arts and General Studies students were classified as "science oriented" if they completed two semesters of majors-level biology and/or chemistry (BIO101 and 102, CHM111 and 112) within the time frame of the data collection. These courses are majors-level introductory science courses for students interested in biology and chemistry degrees, although they can be used to fulfill general education science requirements as well. This subset does exclude students who completed these introductory science courses before this time frame or at other institutions. Course numbering is consistent throughout the VCCS. Many students take courses at several of the VCCS colleges, and these courses are automatically considered for prerequisite completion. Courses taken outside the VCCS at other institutions go through a credit evaluation process but can also be used as prerequisites. Advanced Placement tests can also be used to satisfy prerequisites, but this is uncommon among PVCC students.

Data were reported based on the final degree awarded, not the initial program of study, as many students switch degree plans after matriculation. Students who did not graduate with a degree from PVCC or who transferred without a degree are not included in the analysis, as we could not reliably track Science degree students who completed the Science 299 capstone course but dropped out, transferred without completing the remaining requirements for the Science degree, or switched to another degree plan before graduating. Demographic information (gender, race/ethnicity, Pell-recipient status, age, and first-generation status) from the graduates of these three programs were further sorted into graduates who transferred within the time frame of the data reporting window; graduate-transfers who completed a bachelor's degree; and by the degree completers' field of study. For the purposes of this analysis, the area of study for bachelor's degree was categorized as natural and physical sciences if it was in the fields of biology, biochemistry, environmental science, chemistry, geology, physics. PVCC routinely distinguishes between STEM and STEM–health programs, so degrees in pre-health and pre-agriculture disciplines such as nutrition science, nursing, and veterinary/animal science were excluded from this category.

Open Data

Redacted raw data, analysis, and code are available at https://osf.io/gdwzh (doi 10.17605/OSF.IO/GDWZH).

RESULTS

PITS Survey

The PITS survey was used to assess the impact of Supervised Study research experience on student psychosocial outcomes associated with persistence in science. Because Supervised Study is a program requirement that all PVCC Science students complete, a hypothetical comparison group, such as Science students who do not complete Supervised Study, does not exist. Therefore, the PITS survey was deployed as a repeated-measures approach, similar to a recent study that assesses short-term research experiences (Hanauer *et al.*, 2018). The survey was administered at both the beginning and end of the Supervised Study course during four semesters between 2018 and 2020. The response rate was 38.1% for the pre survey and 46.0% for the post survey. The PITS instrument includes 36 questions organized into six categories: project ownership–content; project ownership–emotion; self-efficacy; science identity; science community values; and networking. Rating scales range from 1 (strongly disagree) to 5 (strongly agree) for all factors except scientific community values, which has a 1 (not like me at all) to 6 (very much like me) scale. As shown in Figure 2, paired responses for students who completed both the pre and post surveys (n = 13) reflect gains in self-efficacy, science identity, science community values, and networking. Among these four factors with positive trends, the range of mean differences between the pre and post survey was smallest for science community values (0–0.8, Δ0.8) and largest for networking (−0.6–2.8, Δ3.4). By contrast, both the content and emotion factors relating to project ownership were mixed. Pearson correlation coefficients between factors show a strong association between self-efficacy and networking (0.673; Supplemental Table S1).

Aggregated data, including all respondents (both paired as well as unmatched respondents) were inspected for similar trends. Supplemental Figure S1 shows quartile distributions by factor for pre and post surveys (n = 22, 29, respectively). Survey responses fell in the middle to high range of the rating scales, with mean responses for each factor ranging from 3.4 to 5.5. The difference between pre and post survey mean question response for each factor ranged from little to moderate positive change (Δ0.12–0.71). Trends similar to what was observed in the paired data are reflected for self-efficacy, science identity, and networking. Responses approached the upper limit of the scale in several instances: self-efficacy (post survey) and science community values (pre and post surveys). To assess the reliability of the survey, a Cronbach's alpha was calculated for the whole survey and each of its constituent parts, showing internal consistency (Cronbach's alpha: $\alpha = 0.94$, 0.93 for pre and post surveys, respectively; Supplemental Table S2).

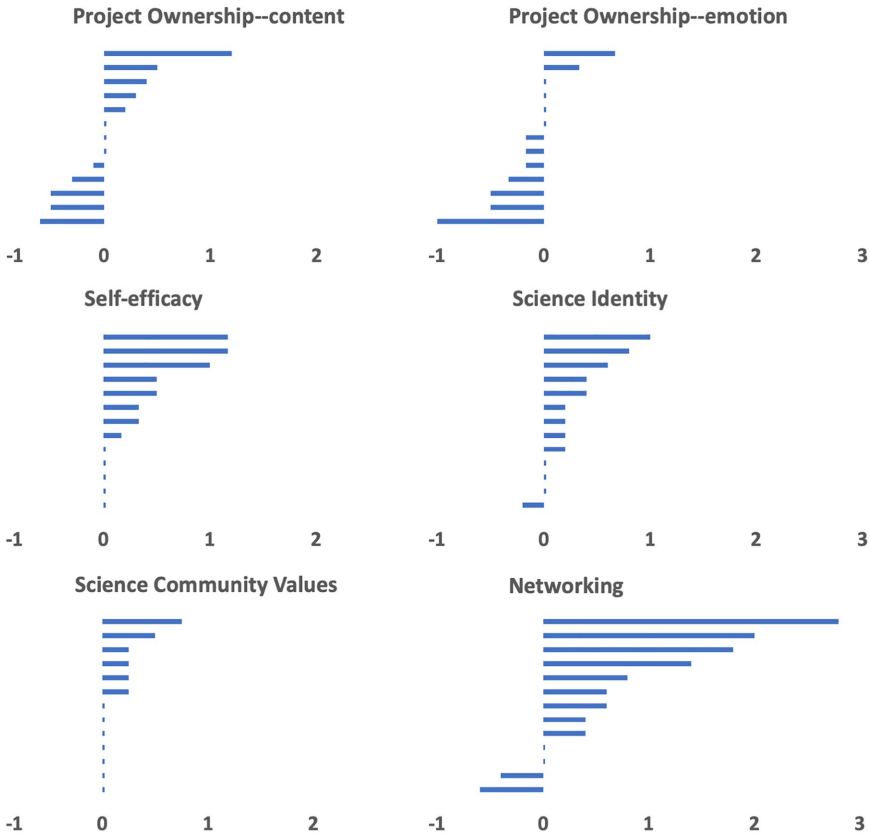

FIGURE 2. Paired pre–post difference by survey factor. Each bar represents a student (n = 13) who completed the PITS survey at the beginning of the course and again at the end of the course. For all six survey factors, the mean difference of question responses is shown, clustered around zero (no change). Survey factors are on a five-point scale from 1 (strongly disagree) to 5 (strongly agree), except Science Community Values, which is on a six-point scale from 1 (not like me at all) to 6 (very much like me).

Respondents to the PITS survey graduate and transfer at high rates (82.4% graduate, 58.8% transfer; Supplemental Table S3) similar to the Science program as a whole and to other transfer-focused programs at the institution. As shown in Supplemental Table S4, respondents to the PITS survey also resemble the Science program in terms of race, ethnicity, and socioeconomic indicators, while older students were slightly overrepresented.

Institutional Data

To assess the ability of the Science program to support degree completion and transfer, graduation and transfer rates were compared across three PVCC programs that share 39–50 credits and that form a common core curriculum (Supplemental Material, Appendix 1). Students in the Science program were compared with science-oriented subsets of students in the Liberal Arts and General Studies programs. In this study, "science oriented" is defined as completion of a majors-level biology and/or chemistry sequence. Table 1 displays the number of graduates and the transfer rates of those graduates from the Science program and for the science-oriented subsets in the other degree programs. There is no significant difference in transfer rates observed between programs: $\chi^2 = 1.801$, $df = 2$, $p = 0.41$, Cramer's $V = 0.05$, 95% confidence interval [0.02, 0.12].

Demographic characteristics for Science degree graduates and for those graduates who transfer are described in Table 2. There is no significant difference in the transfer rates of Science program graduates according to race/ethnicity for Asian, Black, Hispanic, other, and white students ($X^2 = 0.995$, $df = 4$, $p = 0.91$, Cramer's $V = 0.06$, 95% CI [0.05, 0.21]). A comparison of transfer rates between white/Asian and non-white/Asian was not significant ($X^2 = 0.364$, $df = 1$, $p = 0.55$, Cramer's $V = 0.035$, 95% CI [0.0025, 0.15]). The small effect size suggests these groups are not different. Younger Science graduates show a trend toward higher transfer rates compared with their older counterparts ($X^2 = 3.5205$, $df = 1$, $p = 0.06$). The effect size for this finding, Cramer's V, was small (0.11, 95% CI [0.01,0.22], Cohen, 2013), suggesting a weak association for age.

To assess persistence in science over time, 4-year completion and the proportion of degrees awarded in the physical and natural sciences were analyzed. Table 3 illustrates the success of graduate-transfers who subsequently completed bachelor's degrees and the share of those degrees in science disciplines. Graduates from all three programs show high bachelor's degree completion rates (56.8–79.4%), while graduates from the Science program completed bachelor's degrees in the physical and natural sciences (61.3%) at twice the rate of the science-oriented Liberal Arts graduates and nearly four times the rate of the science-oriented General Studies graduates. Physical and natural sciences include biology, chemistry, physics, geology, and environmental science, while excluding pre-health and pre-agricultural disciplines such as nursing, dentistry, and animal science.

While race/ethnicity distributions were constant across students who do or do not complete a bachelor's degree (as shown in Supplemental Table S5), differences were observed for degrees in the physical and natural sciences. Table 4 shows that Science program students from underrepresented groups completed bachelor's degrees in the sciences at a rate comparable to

TABLE 1. Two-year completion and transfer rates for Science and science-oriented students in General Studies and Liberal Arts showing number of students awarded an AA in Liberal Arts or AS in General Studies or Science from PVCC between 2012 and 2020 and rate of transfer to a 4-year institution

PVCC degree program	Awarded AA/AS (n)	Transferred % (n)
Science	177	68.4 (121)
Liberal Arts (science-oriented subset)	81	87.7 (71)
General Studies (science-oriented subset)	183	80.3 (147)

TABLE 2. Demographics of PVCC Science program graduates and graduate-transfers[a]

Characteristic	Awarded AS in Science % (*n*)	Transferred % (*n*)
Total	100 (177)	100 (121)
Female	50.0 (89)	70.8 (63)
Male	49.1 (88)	65.9 (58)
Black/African American	6.8 (12)	58.3 (7)
Other*	4.5 (8)	62.5 (5)
Hispanic/Latinx	6.2 (11)	54.5 (6)
White, non-Hispanic	77.4 (137)	68.6 (94)
Asian	5.1 (9)	100.0 (9)
Age ≤ 24 at time of admission	80.0 (142)	75.4 (107)
25 or older at time of admission	19.8 (35)	40.0 (14)
First-generation	22.0 (39)	71.8 (28)
Pell recipient	33.3 (59)	69.5 (41)

[a]Graduation and transfer data are stratified by gender, race/ethnicity, age, and socioeconomic indicators. Between 2012 and 2021, a total of 177 students graduated from PVCC's Science program; of these, 121 students transferred to a 4-year institution. Other race/ethnicity includes: a combination of two or more races ($n = 3$), unknown ($n = 4$) and Hawaiian/Pacific Islander ($n = 1$).

that of white/Asian peers and at two to four times the rate of students from underrepresented groups from the science-oriented students in other programs.

DISCUSSION

This study explores how a community college science program with a required research experience in the second year supports persistence in the sciences. Psychosocial indicators of persistence were assessed during the required Supervised Study research experience, while academic persistence was analyzed by tracking transfer and bachelor's degree completion rates. Survey results suggest that Supervised Study influences students' perceptions of their educational experience, and analysis of matriculation data shows that Science students persist in science through the bachelor's degree, regardless of demographic factors. Taken together, these observations suggest that the Supervised Study model could boost retention in the sciences, especially for historically underrepresented students, by making early, authentic, independent, mentored research possible and required across a wider range of community colleges.

Hanauer and colleagues designed the PITS survey for use in course-based research experiences and validated the instrument as having high internal consistency in its ability to assess persistence in the sciences (2016). Since then, it has been used approximately two dozen times to evaluate different kinds of undergraduate research experiences, with the consistent finding that these experiences are associated with positive changes in students' perceptions compared with traditional laboratory curricula. The PITS survey has been shown to be an effective tool for comparing different types of undergraduate research experiences (Hanauer *et al.*, 2018) and was used here to provide insights into the Supervised Study experience.

As described, Supervised Study does not fit neatly into a single existing model for undergraduate research, because it combines various instructional and research elements: a research methods course and community of practice; independent, authentic student research projects; and one-on-one faculty mentoring. Because all Science students are required to complete Supervised Study, a control group lacking this experience did not exist. Therefore, the PITS survey was administered in a repeated-measures design, given at the beginning and end of four recent semesters of Supervised Study. Results reveal gains for several factors: self-efficacy (confidence in one's ability to function as a scientist); science identity (how one sees being a scientist as part of who one is); science community values (the internalization of scientific community values such as "discussing new theories and ideas between scientists is important"); and networking (how much one discusses one's research with different people). The most pronounced changes were observed for the networking factor, reflecting the focus on scientific communication throughout the semester. During class meetings, students have many opportunities to talk about their research and to exchange ideas with peers, faculty, lab managers, and course alumni. These discussions are low-to-medium stakes, involving regular check-ins and a slightly more formal midsemester report. At the end of the semester, a formal written abstract and a public poster session give students the chance to communicate their findings to the college community. Hanauer and Hatfull (2015) show that project ownership is predictive of

TABLE 3. Bachelor's degree (4-year) completion overall and in the physical and natural sciences for students awarded an AA or AS degree from PVCC before transferring between 2012 and 2019

PVCC degree program	2012–2019 Graduate-transfers (*n*)	Bachelor's degree awarded % (*n*)	Bachelor's degree awarded in physical and natural sciences % (*n*)
Liberal Arts (science-oriented subset)	63	79.4 (50)	30.0 (15)
General Studies (science-oriented subset)	125	56.8 (71)	15.5 (11)
Science	113	66.4 (75)	61.3 (46)

TABLE 4. Proportion of PVCC Science and science-oriented Liberal Arts and General Studies graduate-transfers who complete bachelor's degrees in physical and natural sciences by race and ethnicity

Race/ethnicity	Science % (*n* science bachelor's/*n* total bachelor's)	Liberal Arts science-oriented subset % (*n* science bachelor's/*n* total bachelor's)	General Studies science-oriented subset % (*n* science bachelor's/*n* total bachelor's)
Black/African American, other, Hispanic/Latinx	62.5 (5/8)	14.3 (1/7)	33.3 (3/9)
White/Asian	60.6 (40/66)	32.6 (14/43)	14.5 (9/62)

networking, a relationship that was not observed in our study. Here, both the project ownership content and emotion factors were mixed or negative. The emotion scale is known to exhibit high variance (Hanauer *et al.*, 2016) which could have contributed to splitting the pattern of responses.

One limitation of this study is that neither the PITS survey data nor the institutional data fully isolate the Supervised Study research experience from other components of the science program, such as widespread course-based research experiences. Future studies could deploy the PITS survey in lab courses with research elements to help pinpoint changes in student perceptions. With a relatively small program that graduates approximately 20 Science students per year, additional semesters of Supervised Study survey data, perhaps stimulated with engagement methods such as gift cards, could provide more confidence as to the origins and patterns of changes in perception. Along these lines, a mixed-methods approach involving interviews would facilitate a deeper exploration of how students understand and experience Supervised Study in the context of a strong Science program.

PVCC students graduating with the AS in Science degree transfer to 4-year institutions at comparable rates to students in the two other transfer-degree programs (Liberal Arts and General Studies) who complete a majors-level science sequence. The vast majority of graduates in these three degree programs transfer (68–87%). The institutional data presented are not sufficient on their own to evaluate the specific effect of the capstone research course on transfer rates but do suggest that PVCC's science-oriented graduates have high transfer rates. However, the 4-year degree completion data strongly suggest that Science degree graduates who transfer are more likely to obtain degrees in the physical and natural sciences than students in Liberal Arts or General Studies. Importantly, students from historically excluded groups who graduate with a Science degree and transfer go on to complete bachelor's degrees in the sciences at similarly high rates compared with their white/Asian peers, echoing the importance of undergraduate research in minority persistence in the sciences (Jones *et al.*, 2010).

Science degree graduates transfer at similar rates regardless of gender, race/ethnicity, and socioeconomic indicators such as first-generation status and Pell-recipient status. Older (25+) Science graduates were the one demographic subgroup in the present study with transfer rates less than 50%. Others have documented that nontraditional students are less likely to graduate compared with their younger counterparts (Taniguchi and Kaufman, 2005). Many nontraditional students enroll in community college to improve their skills for employment and are not necessarily interested in earning a 4-year degree (Shapiro *et al.*, 2015). Anecdotally, a few students in the 25+ category are known to have entered PVCC with a bachelor's degree in a non-science discipline and subsequently completed the AS in Science with the intention of entering the workforce in science-focused jobs that require a bachelor's credential and science training. While this was not tracked for the purposes of the present study, this information does provide insight into a potential reason some of these older students do not transfer to a 4-year institution.

Overall, PVCC science-focused graduates in the three focal degree programs transfer at a high rate compared with PVCC's average bachelor's completion rate of 35.7% between 2013 and 2019 (www.pvcc.edu/transfer-success; data include all transfers regardless of PVCC graduation status). While transfer and subsequent bachelor's degree completion rates can depend on a number of factors, PVCC students are in proximity to several 4-year public institutions, and all VCCS students can take advantage of the state-wide guaranteed admissions program. Finally, the prerequisites for PVCC's general biology and chemistry sequences might also influence transfer and eventual bachelor's degree attainment in science-oriented students, regardless of degree plan. Since 2012, students enrolling in the first course for PVCC's majors-level biology sequence were required to demonstrate success in Intermediate Algebra, which is a slightly more demanding requirement compared with other schools in the VCCS. Students enrolling in the first course of majors-level chemistry were also required to take Precalculus as a co-requisite, whereas other VCCS schools require readiness for Precalculus but do not list it as a co-requisite. Although the effects of math readiness on transfer rates are not separated here, previous work has shown that math readiness is a predictor of STEM transfer success (Cohen and Kelly, 2020), as is chemistry course completion (Cohen and Kelly, 2019).

Future studies could evaluate whether there are differences in postbaccalaureate/graduate enrollment between the Science graduates who complete bachelor's degrees in the sciences and similar students in the two other degree programs. In addition, it would be worthwhile to examine how often Science graduates sought out research opportunities after transfer compared with science-oriented graduates in Liberal Arts or General Studies, which could further evaluate whether increased confidence in pursuing research is a positive outcome from the research-focused capstone course.

Cejda and Hensel (2009), in a survey of undergraduate research at community colleges, stated that institutionalization of research into the curricula was a major barrier to sustainability. Hewlett (2009) called for restructuring of community college faculty teaching responsibilities as a key component of making undergraduate research sustainable and also proposed a model in which faculty establish a research program and then engage students in those programs. While PVCC's model does restructure faculty responsibility by providing teaching credit for the course coordinators, it differs from Hewlett's (2009) model by eliminating the need for faculty to sustain a discrete research program and instead focuses on student-led projects that fit within broad faculty expertise and feasibility. It also requires all full-time science faculty to mentor students in the Supervised Study, so there is a shared departmental culture, with faculty invested in the success of the course.

The longevity and stability of the Supervised Study at PVCC suggests that independent, mentored research experiences built into the curriculum are both practical at the community college level and effective at producing measurable outcomes in student success. This model might help address barriers that often arise when attempting to develop research courses or include research experiences in laboratory courses, such as faculty time, training, lab equipment and space (Spell *et al.*, 2014). One specific benefit of making research required and a component of a degree plan is that federal financial aid can be used for required courses but not for optional courses. This model works with students who cannot sacrifice the prospect of continued employment to participate in optional, short-term research experiences,

even those that include stipends. PVCC's undergraduate research model allows all Science students to participate in a potentially transformative experience early in their undergraduate educations. Although the success of PVCC's Science students in attaining bachelor's degrees in physical and natural sciences could be the result of the overall curricular structure, self-selection into the degree, or other factors, the positive trends seen in some aspects of the PITS survey and the difference in science degree attainment after transfer between Science students and similar students in other degrees suggest that Supervised Study has positive effects on real measures of persistence in science. Critically, after more than a decade of implementation, the model has proven sustainable and has been institutionalized.

CONCLUSION

As with other undergraduate research experiences, Supervised Study has a positive impact on multiple psychosocial factors associated with persistence in science, such as self-efficacy, science identity, science community values, and networking.

At PVCC, Science students and science-oriented students in the Liberal Arts and General Studies programs transfer at similarly high rates. Students who graduate from the Science program transfer at similar rates regardless of gender, race/ethnicity, first-generation status, and socioeconomic indicators. Science program graduate-transfers complete bachelor's degrees in the physical and natural sciences at two to four times the rate of their science-oriented peers in other programs. Notably, these science bachelor's completion rates are high among students from historically underrepresented groups, suggesting that the PVCC Science program, distinguished by its mentored, independent research experience supports continuing involvement in the sciences for broad groups of students.

Supervised Study is a successful model that other colleges can use to develop independent, mentored research experiences for undergraduates.

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