Supporting and Mentoring the Next Generation Scholars in Applied Mathematics (SAMs)

1. General Motivation

Over the past 50 years, UC Santa Cruz (UCSC) has evolved from a liberal arts oriented university to one in which STEM field research has regularly been ranked very highly (cf. US News & World Report for Public Universities and Global Universities rankings). Today, UCSC hosts a total of ~19,700 students, including ~17,800 undergraduates (90%) and ~1,900 graduates (10%). The overall demographics of UCSC is quite diverse, see Table 1. UCSC has been a Hispanic Serving Institution (HSI) since 2012 and was ranked *first in the nation* for Hispanic/Latinx students in 2014 by the site Bestcolleges.com, with first-year retention rate of 91 percent and 74 percent graduation rate overall.

STEM education at UCSC is mainly offered in the **Baskin School of Engineering** (BSOE), which hosts undergraduate and graduate programs in many engineering disciplines traditionally associated with the Silicon Valley (e.g. Computer Science, Computer Engineering, Electrical Engineering (ABET accredited), Computational Media, Statistical Science, Applied Mathematics, etc), as well as in the **Division of Physical and Biological Sciences** (PBSci), which hosts programs in other strongly quantitative STEM disciplines such as (Pure) Mathematics and Physics. Owing to the close proximity of UCSC to the Silicon Valley, where the demand for skilled graduates in strongly quantitative STEM fields (Math, Physics, Engineering) at all levels is growing relentlessly, enrollment at UCSC is also growing very rapidly: the population of strongly quantitative STEM frosh has doubled between 2013 and 2018. The demographics of these majors this academic year (as of Fall 2018) is shown in Table 1.

Table 1: UCSC undergraduate demographics & SciCAM demographics for AY 18/19 (Fall 18)

AY 18/19	Total	Female	URM	1st Gen	Pell Grant Recipients
Undergrads	17,792	8,611 / 48%	5,705 / 32%	6,497 / 34%	6,651 / 37%
Comp. Eng	686	109 / 16%	159 / 23%	210 / 31%	213 / 31%
Comp. Sci	2190	437 / 20%	326/ 15%	567 / 26%	611 / 28%
Elec. Eng	271	42 / 15%	83 / 31%	101 / 37%	102 / 38%
Mathematics	341	113 / 33%	100 / 29%	131 / 38%	116 / 34%
Physics /Astro	437	119 / 27%	115 / 26%	129 / 30%	149 / 34%
SciCAM	**15**	**2 / 13%**	**0 / 0%**	**0 / 0%**	**N/A (Grad program)**

There is today a very significant demand for a workforce with strong computing *and* analytical skills, that can come up with innovative and optimal solutions to complex quantitative problems, regardless of the application in mind. These kinds of skills are precisely the hallmark of Applied Mathematicians. The department of Applied Mathematics at UCSC, hosted by the BSOE, offers two graduate programs that train students to become experts in these areas: a MS/PHD program in Applied Mathematics, mostly designed for PhD students, and a terminal MS program in **Scientific Computing and Applied Mathematics** (SciCAM), that is the central component of this proposal. The Lead PI, **Pascale Garaud**, is graduate director for these programs and the founder of SciCAM. At the present, the combined programs host about 25 PhD students, and about 17 MS students (15 of whom are in SciCAM). Typically, about half of the graduates of both our programs continue in academia (from MS to PhD, or from PhD to postdoc, or become lecturers/teachers), and half find employment in the industry. The number of students who exit without any degree at all is quite small and has been limited to MS students (about 1 per year at

most over the past 5 years). The latest institutional survey of the overall graduate student population in the department confirmed high level of satisfaction with the program.

The AM department has a limited number of Teaching Assistantships to offer to its graduate students each year, and PhD students have priority. A a result, there are only a few positions available to MS students in any given year, and MS students are typically 'self-funded'. In order to support strong MS students to persist to graduation by reducing the burden of graduate school costs, the SciCAM program has recently introduced a 1-year accelerated pathway, that follows from selected quantitative PBSci and BSOE undergraduate degrees to form a 4+1 program. Students in majors such as Mathematics, Physics, Computer Science, Computer Engineering, and Electrical Engineering, who all take the same foundational courses anyway (e.g. Calculus, Linear Algebra, Ordinary Differential Equations, Multivariate Calculus), can take a few selected upper division electives in Applied Mathematics that complement their majors, but at the same time serve as prerequisite courses for the MS, hence enabling them to complete it in 1 year only. Other advantages of the 4+1 program is the **waiver of the GRE requirement** (which is very popular with all students), and **reimbursement of the application fees** as long as they decide to stay in the MS. The 4+1 program, though still very young, has so far been successful in allowing students to graduate in 1 year:

- The first cohort of 4+1 seniors (AY 16/17) had 8 students, 4 of whom joined the MS program; all of them graduated in under a year; 2 later joined our PhD program, one joined a PhD program in Colorado State, and one is now employed by Lawrence Berkeley National Lab.
- The second cohort of 4+1 seniors (AY 17/18) had 6 students, 4 of whom joined the MS program; all of them are presently on track to graduate in 1 year.
- The third cohort of 4+1 students (AY 18/19) so far has 5 students (2 seniors and 3 juniors), and the two seniors have been admitted to start the MS program in the Fall of 2019.

The SciCAM program also trains students who did not come through the 4+1 program, either from UCSC or from elsewhere. SciCAM alumni are doing well, having either joined PhD programs here or elsewhere (e.g. Colorado State, Dartmouth), or found employment in national labs (e.g. Lawrence Berkeley, Lawrence Livermore) or in industry (e.g. Microsoft, Sojern). Three so far have left without a degree, one for health reasons, one for financial reasons, and one because he was offered a PhD position elsewhere.

We have however found that there is a strong disconnect between the number of students who express enthusiasm in the 4+1 program after short informational sessions (typically around 20 each year), and those who actually enter the 4+1 pathway (with an attrition rate of 50-75%). A major difficulty we have encountered so far is in tracking the academic path of these students and keeping in touch with them, since they are from different majors in different divisions, and tend to meet with different advisers who are not familiar with the 4+1 program. A further attrition occurs between the senior and MS year, where some 4+1 students decide not to apply to the MS after all, presumably due to financial concerns. As a result, students in the SciCAM program primarily come from educationally and economically privileged backgrounds with a large representation of non-minority male students (see Table 1). This is in stark contrast with the demographics of UCSC overall. **Reducing the discrepancy between the demographics of majors leading to the 4+1 (Math, Physics, Comp. Sci, Comp. Eng and Elec. Eng), and that of SciCAM itself, is one of the main issues we aim to address**.

Compounding this issue is the fact that Applied Mathematics is not very well known as an academic discipline, and yet, feels more approachable and societally relevant than Pure Mathematics for many. Among the marginalized (low income/first generation/URM) student applicants to our MS programs, a majority have reported very similar situations in their application essays: that they initially struggled in another degree, discovered applied mathematics and/or scientific computing late, and finally discovered their passion as well as a genuine motivation to excel.

Our ultimate goals, therefore, are the following:

a. To increase the awareness of applied mathematics for marginalized student populations, as well as of its use in industry/research of various disciplines.

b. To develop a cross-divisional advising support structure within UCSC that will ensure academic preparation of students (regardless of major) towards enrolling into the 4+1; To increase enrollment of marginalized student population into the SciCAM graduate program at UCSC (without reducing other enrolment), so that demographics of program approach that of majors that lead to it.

c. To support marginalized students in developing an Applied Math identity through internships, meaningful connections with role models, and exposure to professionals in the field.

d. To support marginalized students to graduate with an MS, and place them into industry or PhD programs.

e. To increase the visibility and perception of UCSC in forming excellent scholars and begin developing ties with industry through corporate sponsorship programs, and other UCs with strong Applied Mathematics PhD programs (for possible Track 3 grant in the future).

f. To develop a reproducible methodology that can be introduced in other universities with Applied Mathematics programs.

2. Results from prior NSF support of S-STEM and STEP awards at UCSC.

UCSC received one NSF STEP (School of Engineering) and three NSF S-STEM awards (two in the School of Engineering and one in the Division of Physical and Biological Sciences). The first 3 listed below focus on the transfer students and the early college years, while the last (S-STATSMODEL) focuses on graduate students in Statistics. The latter being the closest one to our proposed work, we describe it in more detail.

(1) PI: Isaacson, Michael: Award Number: NSF-0336517. Award Amount: $2,000,000. Support Period: 9/1/2003-8/31/2009. Title: Developing Effective Engineering Pathways (DEEP). Results: Intellectual Merit: DEEP created pathways from Silicon Valley schools through Foothill and De Anza Community Colleges to UC Santa Cruz. DEEP increased the number of URM students who enrolled in STEM majors across the UC system. The number of URM engineering graduates at UCSC grew by 56% from baseline. Broader Impact: Significantly improved STEM pipeline from community colleges to the UC system. Bibliography: none. Research Product(s): Moran, Carroll and Jaimie Vargas, "DEEP Students' Point-of-View," *Partnerships in Education*, 6(1):3, 2006.

(2) PI: Belanger, David: Award Number: NSF-0850384. Award Amount: $2,000,000. Support Period: 9/1/2009-8/31/2015 Title: *Supernova*: Seeding Talent in Physics and Astrophysics to Prepare the Next Generation Workforce in the Bay Area. Intellectual Merit: *Supernova* brought 25 community college students to UCSC to study physics or astronomy. Scholarships ranged from $3,300 to $37,000, with an average of $17,654. Created introductory course to help incoming transfer students succeed in upper-division courses. 18 students graduated (72%), with 16 of them staying in their declared physics major and two switching to other STEM programs. Six of the graduates were women. Broader Impact: Course piloted for transfer students expanded to include all students. Presented on *Supernova* at 2012 AAPT Physics Chairs Meeting. Bibliography: none. Research Product(s): none.

(3) PI: McDowell, Charles: Award Number: NSF-0807229. Award Amount: $597,999. Support Period: 08/15/2008-7/30/2015. Title: Assisting CS, CE, and EE Student Success (ACCESS). Results: Intellectual Merit: ACCESS supported three cohorts for a total of 41 financially-disadvantaged students through their first two years. Scholarships ranged from $4,500-25,900, with the most typical award amounts being $6,000 and $8,250. Of these students, 32 graduated, and of those students, 25 (87%) received their

degrees in STEM fields. Broader Impact: Success of program helped secure additional scholarships from eBay and the Baskin Foundation. Bibliography: none. Research Product(s): none.

(4) PI: Prado, Raquel: Award Number: NSF-0849831. Award Amount: $276,000. Support Period: 02/15/2009-3/31/2015. Title: S-STATSMODEL: Scholarships in Statistics and Stochastic Modeling. Results: Intellectual Merit: Built a three-tiered model of support with individual mentoring, cohort-building, and peer engagement. Developed cohort-based course on research deconstruction and teaching practices. Broader Impact: Workforce development of women, low income and URM students. Bibliography: none. Research Product(s): none.

The S-STATSMODEL (Scholarships in Statistics and Stochastic Modeling) program was designed to increase the number of academically talented but financially disadvantaged students who complete graduate degrees in the former Department of Applied Mathematics and Statistics (now two separate departments). 20 students in cohorts of four received scholarships. Eight completed a Ph.D. with another three still working toward that degree (one is pursuing her Ph.D at Brigham Young University after completing her master's at UCSC). Six completed a master's degree. Three withdrew without a degree, two leaving for industry jobs and one becoming a physics instructor at Diablo Valley College. 100% of graduated S-STATSMODEL fellows are satisfactorily employed in their field. One former student is now an assistant professor at Brigham Young University; another is a professor at Merced College. One is a research collaborator at the Naval Postgraduate School. Others are employed by, e.g., Lawrence Livermore Labs, Looker Data, YouGov, Cengage Learning, Cogo Labs, the Children's Oncology Group at UCLA, and Stitch Fix as data scientists, statisticians, support analysts, survey analysts, and postdoctoral researchers.

Institutional lessons learned: The success of this program is due to interrelated forms of support. Students met regularly with their advisor and the PI, and were mentored by other doctoral students and postdoctoral fellows affiliated with the department (individual level). Incoming S-STATSMODEL fellows enrolled in a course about research and teaching in the AMS department (graduate cohort). Fellows participated in summer research projects or internships in summer, and presented at UCSC graduate research symposia and conferences.

We are building on the success of the S-STATSMODEL by keeping its salient elements (individual mentoring of students, opportunity to meet role models, and holistic support approach). However, this proposal now has an Applied Mathematics focus, and has been reoriented from working exclusively with graduate students to developing bridges between undergraduate and graduate school, starting with juniors (3rd year). It is primarily designed to recruit students from within UCSC's own diverse applicant pool, with some flexibility to invite students from other colleges if needed. This proposal, as we shall demonstrate, is also more deeply integrated with existing campus infrastructure and support. It introduces students to research early using inquiry-based learning with the goal of helping them develop a STEM identity. Finally, it focuses on creating better mentor/mentee relationships to increase retention and graduation rates, through the development and implementation of training workshops for both mentors and mentees.

3. Plan for implementation

In order to achieve the goals a.-f. listed in Section 1 of this proposal, we have worked with various existing programs on the UCSC campus, to develop a holistic academic and peri-academic support plan to help low income students (1) develop awareness and enthusiasm for Applied Mathematics (Liu et al., 2017; Mau, 2016), (2) complete their studies while developing a identity as a professional Applied Mathematician (Holmegaard, et al., 2014; Black et al., 2010), (3) graduate with an MS and enter

academia (PhD) or the workforce with confidence, and all of this while reducing, in as much as possible, their financial insecurities so they can reach their full potential stress-free (Andrews & Wilding, 2004). In addition to this plan, we have also outlined a number of research questions that will be investigated by our team, and have created rubrics for assessment of the success of the program. These are described in Sections 8 and 9. Our plan begins with the recruitment of "candidates" to the **Next Gen. SAM program** in the junior year, and their follow up through to the end of their MS and beyond.

(1) Increasing awareness of Applied Mathematics and recruitment into the program

Almost all low income students entering UCSC as frosh or transfer are supported by the existing Educational Opportunity Program (EOP, see description in *Facilities, Equipment, and other Resources*), directed by Co-PI **Pablo Reguerin**. Many of the students have self-declared general interest in strongly quantitative STEM fields, although it is common for them to switch from one STEM major to another within the first 2 years (see Section 6), which could imply switching from BSOE to PBSci or vice-versa. As such, we will primarily be working with EOP counselors (rather than divisional counselors) to advise STEM low income students regardless of their majors.

Institutional studies over the last 5 years show that the vast majority of EOP students in majors such as Math, Physics, Comp. Sci, Comp. Eng, and Elec. Eng. will have completed the core set of lower division mathematics and programming courses (Calculus I, II and III, Intro to Linear Algebra, Intro to Ordinary Differential Equations & Intro to Programming) by the end of their sophomore year. Over the summer between 2nd and 3rd year, we will email these students, as well as all low income transfer students (as identified by EOP) who have completed equivalent courses in community college and are entering one of these majors, to invite them to participate in an **"Introduction to Applied Mathematics" workshop** to be held within the first month of the Fall quarter of their junior year. We anticipate being able to accommodate around 50 students each year. This email campaign will be one of the three subjects of CoPI **Rebecca Covarrubias**' research (see Section 9).

The workshop will be designed by AM faculty (**Garaud**, and CoIs **Marcella Gomez, Nic Brummell** and **Dongwook Lee**) and AM graduate students. This will be done as part of the Institute for Science and Engineer Educator Professional Development Program (ISEE PDP, see *Facilities, Equipment and other Resources* for more information) led by collaborator **Lisa Hunter** (see supplemental information for letter of support), which trains early-career STEM academics to develop inclusive inquiry-based learning activities that are shown to support persistence to degree (Braxton & Francis, 2018). The success of the PDP is well documented (Ball & Hunter 2010; Metevier et al. 2010; Seagrove et al. 2010). Participating AM graduate students will in the process learn about inclusive teaching and will design an immersive applied mathematical inquiry experience that will engage students in authentic AM problems, and give them a first opportunity for cohort development by working in collaborative teams (Bryson & Hand, 2007).

The workshop itself will invite participating EOP students to reflect on discipline-based questions (National Research Council, 2012) such as "What is Applied Mathematics", "What careers are available to Applied Mathematicians", and "How can Applied Mathematics save the world". We will use outreach material readily available from the Society for Industrial and Applied Mathematics (SIAM) website as a starting point, and will further develop our own. The workshop will then offer the AM inquiries designed in the PDP to introduce students to various applied mathematical topics taught at UCSC (fluid dynamics, control theory, mathematical biology), and to discover the power of mathematical tools in answering interesting scientific and societal questions. The ISEE PDP emphasizes identity development, and how to support identity development through inquiry experiences (Bransford, et al., 2000), which ideally addresses the goals of this activity.

At the end of the workshop, all participating students will be given the option to become "candidates" to the **Next Generation Scholars in Applied Math** (**Next Gen. SAMs**) program (EOP

students who did not have the opportunity to participate in the workshop, but wish to become candidates, will also be given the same option). Throughout their junior year, candidates will be required to meet regularly with a dedicated EOP/SAM adviser familiar with the program, as well as with the Lead PI. Both will work with the students to ensure that they take the correct courses in preparation for application to the 4+1 program. This will be done with the support of UCSC's new online advising system, **Slug Success**, which allows all counselors (college, divisional, etc.) to ensure candidates take the appropriate courses, meet all required benchmarks and stay on track. The process will serve as a model for a new campus-wide approach to counseling that relies on early alert information that has been shown to support student success (Tampke, 2013).

Students who stay on track and maintain a minimum GPA (in the major) of 3.3 will be invited to apply to the 4+1 program during the Spring quarter of their junior year. Those who *also* satisfy the NSF S-STEM eligibility criteria will be invited to submit the additional material to apply to the scholarship program (see Section 5). Advice in preparing the application will be provided by the dedicated EOP/SAM adviser. The selection of the **6 Next Gen. SAMs** will take place in June (see Section 6 for a justification of the number of scholars, and selection criteria), with effective start date in the Fall of their senior year. No plans are made for the summer between junior and senior year to allow the future scholars to complete courses as needed (through summer session), or find summer employment to support persistence through financial security (Cabrera et al., 1992).

(2) Next Gen. SAMs: developing an Applied Mathematics identity; academic preparation for the MS.

A scholarship of $10K per scholar will be provided during senior year, to lower their financial burden so they do not have to work during their studies. It is indeed crucial to their progress within the tightly scheduled 4+1 program that each scholar be able to study full time (i.e. three 5-credit courses per quarter). The scholarships will be distributed as $3K each academic quarter (pending satisfactory progress & maintenance of eligibility), and $1K for the summer. See Section 6 for a summary of student needs and rationale for the scholarship amount and distribution.

The Next Gen. SAMs will be transferred from the EOP to the UCSC MESA Engineering Program (MEP, see description in *Facilities, Equipment, and other Resources*) directed by CoPI **Carmen Robinson**. Bringing them together under the MEP umbrella is necessary to help cohort building despite their different majors. Together, scholars will benefit from the MEP existing support services, including a dedicated study center located on the same floor as the Applied Mathematics department, a quiet work area, free snacks, a book lending library, individual and group tutoring, and invitation to attend the MESA conference (which develops student leadership skills and networking skills, provides career preparation advice, etc.). Funds are requested for the scholars to attend that conference if they wish to do so (or others, see below). The MEP also organizes a number of free workshops, including a Linkedin workshop (for juniors and seniors) and an alumni workshop.

Senior SAMs will take 2 or 3 of the required upper division preparatory courses together, (Numerical Methods, Introduction to Applied Mathematics, and Introduction to Scientific Computing), which will continue the process of cohort building introduced through the junior workshop. In order to provide the Next Gen. SAMs with role models in Applied Mathematics they may identify with, informal monthly brown-bag lunches will be held inviting seniors and MS scholars, as well as PhD students and faculty in AM who identify as coming from marginalized (low income, URM, first generation) populations (this year, this includes CoI **Marcella Gomez**, as well as current 6 PhD students). This is in addition to the weekly AM social events that are hosted anyway, and to which the scholars will also naturally be invited. The scholars will also be invited to attend and contribute (voluntarily) to the AM student seminar series. These seminars are by contrast specifically not attended by any faculty, giving the students the opportunity to share their research without any pressure, and to learn from their peers; they are very popular.

It is anticipated that most Next Gen. SAMs will complete their undergraduate studies in the Spring of their senior year. A special ceremony is held in June celebrating all graduating MEP students, and the scholars and their families will be invited to join that event in addition to the events associated with their own major graduation.

To crystallize their identity as Applied Mathematicians, senior scholars will be strongly encouraged, and given assistance, to secure an internship for the summer between their senior and MS year. Since some of them may already at that point have decided whether they prefer a career in industry vs. national laboratory vs. academia, we will not impose the format of that internship, and let the scholar decide what they prefer. However, *each scholar will have a dedicated faculty mentor, whose role is to help them secure such an internship, either in their own research lab, or elsewhere*. If elsewhere, then the mentor will provide the scholar with a list of opportunities (e.g. research in a different lab, UC Leads program; REU programs; National Lab Internships; Industry Internships), and guidelines as to how to find and apply to these opportunities, early in the Fall quarter. In alignment with educational research in STEM education that finds design thinking, performance assessment, and activity theory improves STEM identity and persistence to degree (Dym et al., 2005; Freeman et al., 2014; NRC, 2012), mentors and faculty will be in regular contact (in person or online) with the scholar throughout the internship (at least once a week), to ensure satisfactory progress and experiences that support learning and persistence. After the internship is completed, the mentor and the student will debrief the experience, and will reflect on what worked, what didn't work, so that lessons can be learned either way.

The Next Gen. SAMs will begin their MS year in the Fall. Pending satisfactory progress and maintenance of eligibility, they will continue to receive a $10K scholarship for a second year, at the level of 3K per academic quarter and 1K for the summer, for the same reasons (see Section 6). Note that we also anticipate the possibility that some 4+1 senior scholars may graduate a quarter early or late. The MS program is sufficiently flexible to allow for such a possibility (this occurs relatively frequently), and have a Winter or Spring start. If that is the case the scholarships will be adjusted accordingly. However, no scholar will receive more than 2 years of funding.

Early in the Fall quarter of the MS year, the AM department will organize for all its students a 1-day career development workshop, including (1) a discussion of available jobs / PhD opportunities for MS and PhD students; (2) a timeline for applications (3) a discussion on best practices for writing a CV and sitting through interviews, and (4) a discussion on grant / fellowship applications. The students will also have the opportunity to meet with alumni (in person or online, depending on availability). This will be followed later in the quarter by the yearly BSOE-wide recruitment fair, where many Silicon Valley companies send representatives to meet and interview interested students.

By the middle of the Fall quarter, the Next Gen. SAMs will have to determine whether they want to pursue a more academic track (and do a thesis, with the goal of applying to PhD programs beyond the MS) or enter the workforce (in which case they will take a comprehensive take-home exam at the end of the year). Students who pursue a thesis capstone with the goal of continuing into a PhD program will be mentored by AM faculty towards the thesis. The thesis must contain original research and publishable work. Students will be encouraged to present the results of their research in national conferences. Funds are reserved to help with registration and travel (in addition to any funds the MS mentor may be able to provide their student), see *Budget justification*.

(3) Graduation, and beyond.

As was the case for the seniors, graduating MS scholars and their families will be invited to a special event organised by the MEP to celebrate their success, in addition to the BSOE-wide graduation ceremony. The Next Gen. SAMs will also be recognized and celebrated in the BSOE newsletter.

Beyond graduation, we hope the Next Gen. SAMs who leave UCSC will continue to be involved in helping future SAM cohorts by joining an alumni network, attending the alumni events, providing

general feedback to the program leadership, and more specific advice to current scholars as needed. Our SAM advisers will reach out to them bi-yearly by email to invite them to various events such as the alumni event, the BSOE corporate sponsors event and the career fair, and to maintain contact. By building closer ties with industries who will be hiring the Next Gen. SAMs, we intend to increase the size and breadth of the existing BSOE corporate sponsorship program. Through this program, we may in the future be able to continue providing scholarships to the Next Gen. SAMs beyond the end of this project period.

4. Activities on which the project builds

(1) Description of existing Student Support Services and Programs

As described in Section 3, candidates and scholars of the Next Gen. SAM program will be supported by the Educational Opportunity Program (EOP), chaired by CoPI Pablo Reguerin and the MESA Engineering Program (MEP), directed by CoPI Carmen Robinson. They will therefore benefit from all of the infrastructure and holistic support provided by EOP and MEP, including dedicated advisers, counselling, free tutoring, free textbooks, etc. A detailed description of EOP and MEP is included in the *Facilities, Equipment and Other Resources* document. Also note that the EOP and MEP naturally work with existing support services on campus such as Financial Aid, Slug Support, and the Counselling And Psychological Services (CAPS).

(2) Description of new activities building on existing ones.

Junior recruitment event: The planned recruitment workshop in the beginning of Junior Year will be developed under the guidance of the ISEE PDP program let by **Lisa Hunter**, and will be modeled closely after the highly successful Workshop for Engineering and Science Transfers (WEST) offered by ISEE/PDP. The 2.5 day WEST event has two goals: (1) community building among cohorts of transfer students in particular STEM fields, and (2) engaging participants in the real process of research through inquiry-based activities. Many other activities are also offered beyond the inquiries, including presentations by students and faculty, career development tutorials, social events, etc. As described earlier, Applied Mathematics graduate students will attend the PDP, and will learn from the vast experience of the WEST developers (including Lisa Hunter and other PDP mentors) how to effectively build cohorts, and how to design engaging inquiries in a culturally-responsive and inclusive way.

Mentoring training: A key element in increasing retention and graduation rates for marginalized students is to provide them with personalized and positive mentorship experiences (Castellanos and Gloria, 2007). Training faculty to become better mentors is essential (Lindén et al., 2013), especially given that the social and educational experiences of faculty tend to be quite privileged (NCSES, 2014).

We will offer 3 mentoring-related workshops to faculty and students. The first two are existing workshops developed by the Center for Innovation in Teaching and Learning *(*CITL*,* see *Facilities, Equipment and other Resources* for more detail) led by collaborator **Jody Greene**. One is designed for faculty, and addresses best practices for mentoring graduate students in general. The other one is designed for the mentees, and dovetails on the faculty mentoring workshop so expectations on both sides align. Both will be offered every year. While the practices discussed in these workshops are generally applicable to all students, we will also offer a third workshop to faculty, on mentoring marginalized students more specifically. The workshop will explore the role of educator mindsets in facilitating student learning, and will provide research-based strategies for developing a supportive learning environment. The workshop has been developed and delivered to multiple staff, student and faculty audiences by CoPI **Rebecca Covarrubias** and her graduate students at the target institution and nationally, and draws heavily from their research work (Covarrubias, Valle, Laiduc, & Azmitia, 2018; Covarrubias, Laiduc, & Valle, 2019; Laiduc & Covarrubias, in prep), see Section 9. It will be offered in the third year of the program, to allow the team time to carefully analyze the results before and after the workshop (see Section 9 for detail).

5. Student selection and retention process

As discussed in Section 3, all students who have been identified as candidates during their junior year will be invited to apply to the 4+1 program. This includes any EOP students who participated in the early recruitment program, as well as any other low income student, who has expressed interest in Applied Mathematics. Criteria for admission into the 4+1 program will include (1) a minimum junior year GPA *in the major* of 3.3, aligned with the honors criterion on campus and (2) a plan to have all MS pre-requisite courses completed by the start of the MS year. Note that we do not require a cumulative GPA because EOP students often have a slower start (with GPA increasing substantially after the first two years), and transfer student grades received prior to UCSC cannot be compared with UCSC grades.

All students who have applied to the 4+1 program who also satisfy the eligibility criteria defined in Section IV.B. of the call for proposals (citizenship, low income, enrolled full time) will be invited to apply for the scholarships at the start of the Spring quarter, with applications due in the middle of May. Students will be required to submit a resume/CV, and write a 1-page essay on what their career plans are, how the scholarship would help them achieve these plans, and how they propose to use theirs careers for societal benefit. A committee consisting of the Lead PI, plus 2 faculty from the AM department, as well as the MEP/SAM adviser, will select the scholars based on their GPA, CV, and essay. The CV will be used to gauge professionalism and maturity / experience, while the essay will be used to gauge the fit of the students' interest with the SciCAM program, and their intent to serve society in the future (which is priority for the UCSC campus). Results will be communicated to the students after Finals week.

Once in the program, the progress of the scholars will be reviewed by the MEP adviser and the Lead PI once every quarter. The scholarships will continue to be provided unless the scholar loses eligibility, or fails to keep a minimum GPA of 3.3 for more than 2 quarters in a row without substantial justification (medical or personal/emotional distress, for instance). If fewer than 6 senior scholars proceed to the MS program for any reason, then all GANN-eligible students admitted to SciCAM (from UCSC and elsewhere) will be invited to submit a similar essay at the end of the summer of their senior year. These will be reviewed by the same committee, and scholarships will be awarded as needed to ensure that a cohort of 6 MS is maintained. A similar principle will be applied in the first year of the program to select MS scholars (before the first cohort of seniors have gone through the program).

6. Rationale for the number and amount of scholarships

We shall offer 12 scholarships of $10K per year, including 6 to seniors and 6 to MS students, with the expectation that each scholar will receive the scholarships for 2 years under normative progress. Adjustments will be made in the first and last year of the program for ramp-up and ramp-down. At a minimum the program will support 30 students over its 5-year duration. The rationale for the number of scholarships and their amount (the maximum allowed) is two-folds.

First, given that each scholar will be given one-on-one mentorship during the summer internship of their senior-to-MS year, followed (for some) by thesis research during their MS year, we must limit the size of the cohort to ensure that they all have a dedicated mentor within the AM faculty (including the 8 permanent members of the department, as well as a similar number of affiliates in other departments).

Secondly, the Financial Aid office estimates that the costs of attendance to UCSC, for a California resident undergraduate, varies between $27K to $37K per year. For California resident graduates, the range is $30K to $44K (estimates for both are for Acad. Year 2019/20, source: UCSC Financial Aid website; tuition and fees alone for CA residents is ~$14K in both cases). The main source of uncertainty in these estimates are the housing costs, which have skyrocketed in the last 5 years;

rent-controlled campus housing is not available to all students. By providing the maximum amount for the scholarships per year we will alleviate the scholars' need to work while they are studying, which will allow them to take the 3 courses per quarter necessary to complete the accelerated MS program in 1 year. The scholarships will be awarded to each scholar, split as $3K per academic quarter, and $1K for the summer. For the academic year, $3K is equivalent to what a student would receive earning $12/hour working 25 hours per week for the 10 weeks of each quarter. For the summer, a small amount is provided to help the scholars either take summer session courses if they need to, or to support themselves financially if they elected to do an unpaid internship on campus. They can also use this amount towards applications to PhD programs should they be interested in this academic path.

To determine whether we can indeed expect at least 6 qualified applicants to the program every year, we can look at Table 2 (provided by UCSC Institutional Research), showing for the last two completed academic years (AY 16/17 and 17/18): (a) The number of declared EOP students in each of the majors leading to the 4+1 program, and corresponding percentage of total number of declared students in the major. These numbers typically include all sophomore, juniors and seniors in the major, and include transfer students; (b) The percentage of EOP students who graduated in each of these majors that year. Note that the total number of declared students is much larger than the number of degrees awarded because it includes all declared sophomores, juniors and seniors, and also because the number of students in some majors especially in BSOE has grown significantly over the past 2 years. (c) The average total GPA of graduated EOP students.

Major	AY	(a) Declared EOP students, percentage	(b)Number & percentage EOP degrees awarded	(c) Average Cum. GPA of EOP students
Computer Engineering	16/17 17/18	44, 31% 52, 33%	16, 28% 16, 27%	3.16 3.24
Computer Science	16/17 17/18	181, 23% 227, 24%	42, 21% 77, 23%	3.20 3.27
Electrical Engineering	16/17 17/18	53, 37% 47, 35%	17, 26% 24, 38%	3.19 3.31
Mathematics	16/17 17/18	66, 40% 63, 36%	26, 40% 40, 42%	3.15 2.89
Physics and Astrophysics	16/17 17/18	43, 35% 45, 35%	16, 35% 10, 23%	3.4 3.3

Table 2: Analysis of EOP student performance at UCSC in strongly quantitative STEM majors

We see that while not all of these students will be sufficiently interested in Applied Mathematics, or have a high enough GPA, to join the 4+1 program, there is a strong likelihood that at least 6 students from all of these majors combined will each year.

We also show in Table 3 a measure of 1- and 2-year retention of EOP students in strongly quantitative STEM majors (Math & Physics from PBSci, and all Engineering majors). Note that switching between these majors is fairly common in early years, especially within the BSOE where boundaries are quite fluid. We therefore show instead the general retention rate into these strongly quantitative STEM majors *as a whole*: for those students who intended to enter either of these majors as frosh in a particular academic year, the table records their present status *as of February 2019*: whether they stayed in any of the strongly quantitative STEM major, changed to a major that isn't strongly quantitative, or left UCSC. Numbers for 2016 therefore illustrate 2-year retention rate, those for 2017 illustrate 1-year retention rate.

Admit year of EOP students, total number:	Stayed in a strongly quantitative major	Changed major to one not quantitatively strong	Left UCSC
Fall 2016: 270	144, 54%	85, 31%	41, 15%
Fall 2017: 265	140, 53%	89, 34%	36, 13%

Table 3: 1- and 2-year retention rate of EOP students in strongly quantitative majors.

7. Significance of project and relationship to the NSF goals

The goals of our proposed work are strongly aligned with the NSF S-STEM goals, and the various activities described in Section 3 have been designed specifically to address these goals.

(1) The junior year recruitment event will introduce students in strongly quantitative STEM fields (Mathematics, Physics, Engineering) to a new field they may never have heard of, Applied Mathematics, and to career opportunities they may not have thought of. While the event is not designed to recruit *new* students into STEM, it may give some students renewed incentive to stay in STEM, and motivation to graduate. As such, it directly addresses both retention & career preparation.

(2) The holistic peri-academic support provided to the scholars, combined with the various activities designed to build an Applied Mathematics identify (internship, student seminars, role models, etc.) and the mentoring by AM faculty, will altogether increase overall student success and graduation rate of low-income students in the SciCAM MS program.

(3) The proposal builds on and adapts to the subject of graduate-level Applied Mathematics existing high-quality students programs and education research at UCSC (e.g. adapting the PDP/WEST program to create the AM recruitment event, adapting Prof. Covarrubias' research on anti-deficit based mentoring practices to design the mentoring workshops - See Section 9.)

(4) By supporting the students in their search for internships, and providing them with personalized career development support, we will ease their entry into academia or the workforce.

8. Assessment and Evaluation of the proposal goals

The evaluation plan includes a summative, yearly report on the efficacy of the SAMs program by *a - f* goal, produced by **Jennifer Quynn**, CITL assessment and evaluation specialist, and made available by December 15th to the NSF, the SAMs program team (instructors, TAs, mentors, academic advisors), and other campus stakeholders. Student grades, enrollment information, and indicators of high school preparation shown to predict student persistence in STEM (Mau 2016), will be included in the report and will be used to judge the efficacy of the SAMs recruitment and selection process. Summative data will be presented in the report longitudinally to allow for understanding program effects and student academic indicators, internships, and post-graduation information, such as entry into further Ph.D. study and/or employment, over time. Summative evaluation of the efficacy of the program will involve multiple measures (Darling-Hammond, 2006), data triangulation (Leech, 2007), and will support validity of findings through identification of irrelevant variance and accounting for any negative social consequences from evaluation (Messick, 1987). The summative evaluation report will track lessons learned in the SAMs program and by the SAMs program team (PI, instructors, advisers, mentors, and others).

The evaluation plan also involves formative assessments and a continuous improvement process, embedded directly into the learning cycle for each cohort, and similar to activities of engineering faculty for ABET accreditation (Verma, 2018). Formative assessment will be done by survey and interview and will be designed and implemented by Jennifer Quynn. These assessments will tap into constructs such as student sense of belonging (Wilson et al., 2014), engagement (Kahu, 2013), STEM identity (Holmegaard

et al., 2014), learning theory (National Research Council, 2000) and persistence (Braxton, 2018), with design informed by previously validated surveys, such as the National Survey for Student Engagement of (NSSE, 2017). The SAMs program team will meet monthly and use assessment data to identify any academic and/or social barriers to persistence, and to determine and document solutions. All barriers and responses will be tracked and used to inform lessons learned.

Evaluation plan by *a - f* program goals (see Section 1)

Goal	*Assessment plan and follow-up (feedback for program improvement)*
a	Students will be surveyed and interviewed, pre- and post- workshop, to measure change in baseline understanding of AM; surveys tools will focus on student engagement, sense of belonging, identify, and persistence. The instructional team will use data to make program improvement decisions that support workshop effectiveness and address shortfalls, as needed.
b	Efficacy of meetings with SAM adviser will focus on data from Slug Success, a software tool used by academic advisers to track student academic progress and tried interventions; the evaluation expert and SAM adviser will identify trends and relay information to the instructional team, and Lead PI; this information will also be used to inform interview and survey items for assessments; summative evaluation will include efficacy of the advising pipeline & of meeting enrollment goal and allow for comparing attendance data from junior year with 4+1 enrollment data;assessment of student academic preparedness (e.g. coursework completion) for MS degree will be included.
c	AM identity will be assessed using survey methods and through interviews with all potential SAMs candidates, and re-assessed throughout the SAMs program to understand if (and how) student identity or "sense of fit" changes; the SAMs project team, including mentors when possible, will be assessed on understanding importance of identity to AM, engagement and other constructs identified in persistence literature; findings will be presented at monthly evaluation meetings and ideas for supporting AM identity will be explored, implemented, with results shared at the following evaluation meeting and as part of program improvement.
d,e	SAMs scholars will be assessed and tracked for 5 years following graduation from UCSC and the 4+1 program; assessments of graduates will include satisfaction with the program, employment decisions and/or Ph.D. study information; these data will be used to inform future decisions for mentorships and to support productive connections for SAMs scholars in the field; employers of SAMs will be interviewed to assess satisfaction with the training scholars are receiving; data from attendance to corporate events will be recorded, and findings will be used to improve both SAMs curriculum and corporate outreach practices.
f	The SAMs project team and evaluation expert will present findings to groups within UCSC and to other UC groups interested in supporting low-income students in STEM; during monthly evaluation meetings, lessons learned by the instructional team will be tracked and summarized, and will be a fundamental topic for presentations at conferences, and in the yearly summative evaluation report.

9. Intellectual Merit: Generation of Knowledge & Dissemination

(1) <u>Knowledge Generation.</u>

Numerous diversity-related initiatives have emerged in response to widening achievement disparities

between marginalized (e.g., low-income, students of color) and majority (e.g., high-income, White) groups in STEM. While promising, these initiatives might further stigmatize program participants by casting them as "needing assistance". This framing largely reflects a *student deficit perspective*, solutions largely focus on "fixing" students (Valencia, 1997). Alternatively, an *anti-deficit perspective* holds institutions accountable for failing to engage students. Deficit thinking has been documented through qualitative research with younger students (Ortiz & Irizarry, 2011; Valenzuela, 1999), yet the exploration of deficit thinking is nearly nonexistent with college students and in STEM settings. In one paper, Castro (2014) analyzed semi-structured interviews with STEM diversity program staff across 10 universities. Discourse analysis revealed that a few staff members held anti-deficit perspectives (e.g., students come from "academically unprepared high schools"), but more than double held student deficit perspectives (e.g., students are "significantly underprepared"). What Castro did not examine was the impact of these perspectives on student outcomes. Thus, the current work sharpens theory by establishing a causal link between deficit thinking and student outcomes.

Given the scarce work of examining deficit perspectives in STEM, particularly in STEM-related diversity programs such as the proposed project, we have three research aims. First, we aim to examine how shifting from student to anti-deficit messaging in program recruitment can reduce stigma and increase program participation among targeted students. Second, we aim to document these perspectives among key program leaders by examining what attributions faculty mentors make for student struggle - whether they reflect student deficit or anti-deficit thinking - and the impact of such attributions on student outcomes. Third, we aim to examine the effects of a research-based workshop on culturally-relevant mentoring on faculty mentors' mindsets and mentoring practices with students.

Aim 1: Assessing Program Recruitment Messaging. Following past work of the research team (Covarrubias, Laiduc & Valle, 2019), we will explore how recruitment messages influence students' feelings of stigmatization and their program sign-ups. Using an online recruitment tool with the first cohort of students in Year 1, we will randomly assign program-eligible students to read 1 of 3 recruitment messages. In the control, students will read factual information about the program. In the student deficit condition, the factual information will be coupled with messages that speak to students needing assistance. In the anti-deficit condition, the factual information will be coupled with messages that shift blame away from students and convey program responsibility. Students will then be asked to complete a stigma consciousness scale, along with other measures, and an item assessing their intent to sign-up for the program. We expect that compared to the control and student deficit conditions, anti-deficit messaging will reduce stigma consciousness and, thus, increase program sign-ups.

Aim 2: Analyzing Faculty Mentors' Explanations for Student Struggle. Building on past approaches with undergraduate tutors at UCSC (Laiduc & Covarrubias, in prep), we will explore STEM faculty mentors' attributions about student struggles and, consequently, their beliefs about ability and mentoring advice. We will target scholars in the Years 1 and 2 of the program to better explore these existing perspectives among faculty mentors. In an open-ended survey, faculty mentors will read a vignette of a struggling student and make attributions for the struggle. We will code attributions as student deficit or anti-deficit. We anticipate more instances of student deficit themes and fewer anti-deficit themes. To examine how these perspectives impact mentoring, mentors will answer questions about student ability and their mentoring advice. We predict that compared to those with anti-deficit attributions, mentors with student deficit attributions will hold more negative judgments about ability (e.g., the student does not have what it takes) and offer more unsupportive mentoring advice.

Aim 3: Shifting Mindsets through a Research-Based Culturally-Responsive Workshop. We will implement and assess the effectiveness of a research-based workshop around culturally-responsive mentoring on faculty mentors' mindsets and mentoring practices. In Year 1 and 2 faculty mentors and mentees will receive 2 standard graduate mentoring workshops developed and hosted by CITL (see

Section 4). In a pre-post test design, the research team will examine faculty mentors' deficit perspectives at the beginning of the year before being exposed to the workshop (T1) and at the end of the year after being exposed to the workshop (T2). We will also administer a brief survey with faculty mentors and their mentees about their experiences at T1 and T2 assessing the quality of the mentoring experience. These early years will serve as baseline measures. In Years 3 and 4, the research team will add and assess a research-based workshop on culturally-responsive mentoring. CoPI Covarrubias' research team has delivered and refined this workshop for multiple audiences, including to large groups of faculty (see Section 4). The research team will then execute the same pre-post test design and administer similar surveys to faculty mentors and students to assess the quality of the mentoring experience. We will compare these responses to baseline measures. We expect that a culturally-responsive mentoring workshop will help shift deficit mindsets and, subsequently, help facilitate more positive mentoring experiences for both mentors and students.

(2) Knowledge Dissemination.

Equity-grounded programming is needed to adequately prepare future generations of scholars and workers from diverse backgrounds. If supported, evidence of the advantages of shifting from student deficit to anti-deficit perspectives can be applied across academic contexts (e.g., student advising, teaching) by reframing perspectives of how people approach, design, and implement their programs. As such, these research findings will be shared within the university—through presentations to partner programs (e.g., CITL, First-Generation Initiative, Student Success Equity Research Center)—and also broadly through publications (e.g., Review of Higher Education) and conference presentations (e.g., American Mathematical Society, American Educational Research Association).

10. Broader Impacts.

This program is specifically designed to provide support, mentoring and scholarships to low income seniors and MS students at UCSC who have demonstrated their ability to strive academically. As shown in Table 1 of this proposal, however, there is a very substantial overlap at UCSC between student populations that are FAFSA eligible (as measured by the number of recipients of Pell grants), under-represented minorities and first generation in their families to attend college. As such, while the Next Gen. SAM program limits eligibility to low-income students, there is a very high likelihood that most of those low income students will also be URM and/or first generation. Hence, supporting and mentoring of URM and first generation students, providing them bridges into graduate school, increasing their retention rate and training them to enter the workforce, are all broader impacts.

As discussed in Section 3, we plan to develop an alumni network of former Next Gen. SAMs, which will build UCSC's reputation for training and placing outstanding students in the workforce. We also plan to participate in the expansion (in breadth and size) of the Baskin School of Engineering Corporate sponsorship program by leveraging the connections developed through the alumni network.

The research proposed by co-PI Covarrubias will establish whether faculty training in anti-deficit culturally-responsive mentoring practices is effective in fostering anti-deficit mindsets, particularly at the graduate level. If training is effective, her research findings will be translated into a template for faculty development beyond UCSC and Applied Mathematics.

11. S-STEM Project Management Plan

Our proposed activities bring together a number of faculty and personnel with clearly defined tasks. None of the CoPIs or PIs are receiving salary from this grant, as the tasks to be performed are part of their standard administrative and/or academic duties on campus.

- Lead PI, Prof. Pascale Garaud, is the graduate director for the AM department. She will manage the overall program, and interact with the EOP, MEP, CITL and ISEE. She will work with the MEP/EOP/SAM adviser to ensure that the correct information is provided to the students. She will meet with the scholars regularly, and no less than once every quarter (in addition to standard office hours), to check in and provide counselling as needed. As a former ISEE/PDP participant herself, she will help with the design of the recruitment workshop. She will work with the other CoPIs and with the evaluator (Quynn) on the production of NSF reports.
- CoPI Prof. Rebecca Covarrubias, is an Assistant Professor in Psychology, faculty director of the First Gen Project, and of the Student Success Equity Research Center (SSERC). With her team of student researchers in the SSERC Dr. Covarrubias will coordinate the proposed research activities described in Section 9, and oversee the development of the anti-deficit mentoring workshop for the Applied Mathematics faculty and graduate student peer mentors. She will also oversee the production, publication and dissemination of the research findings with her graduate students.
- CoPI Dr. Carmen Robinson, is the Director of Undergraduate Affairs at the BSOE, and the acting Director of the MEP. She will co-lead the hire and training of the adviser dedicated to our scholarship program (see below), as well oversee the activities that are provided by MEP.
- CoPI Dr. Pablo Reguerin is the Associate Vice Chancellor for Student Achievement, Equity, and Innovation, and the Director of the EOP. He will co-lead the hire and training of the adviser dedicated to our scholarship program, as well as overseeing the activities that are provided by EOP.
- A dedicated EOP/MEP/SAM adviser (to be determined) will be identified and hired (at 20% time). The adviser will be affiliated with both EOP and MEP, and will regularly meet with the students (once a month) to check in with them about any issue they may be encountering. The adviser will work to expand existing MEP programs (e.g. book lending program, career counseling and workshops, private tutoring) to include senior and MS-level Applied Mathematics as a supported subject area. The adviser will be responsible for all communications with the program scholars before, during and after their participation, and for data collection for NSF reporting purposes.
- Dr. Jennifer Quynn, assessment and evaluation specialist and STEM equity developer at the Center for Innovations in Teaching and Learning will be hired for 12 days per year to develop and implement assessments, analyze data and report on findings, and to organize and facilitate the monthly formative evaluation meeting with the SAMs program team. She will prepare and present the NSF yearly summative report for NSF and make the report available to campus stakeholders.
- CoIs Profs. Marcella Gomez, Nic Brummell, & Dongwook Lee are faculty in the AM department, and will participate in the development of the outreach workshop. All faculty in the AM department will participate in mentoring senior and MS scholars, as is required in departmental policy.
- Dr. Jody Greene and Lisa Hunter are the directors of CITL and ISEE respectively. They have provided letters of support to describe the commitments of CITL and ISEE to the Next Gen. SAM program (see *Supplemental Documentation*), such as the 2 mentoring workshops, and development of the recruitment workshop. They will oversee these activities in collaboration with the Lead PI.
- Graduate students in the AM program will actively participate in the development of the recruitment workshop. They will attend the ISEE Professional Development Program in years 1-3, and will lead the design and redesign (in later years) of the workshop, with the help of ISEE mentors. Other graduate students in the AM program will help, both prior to the event, and during the event. They will also participate in peer mentoring events (brown bag lunches, student seminars, tutoring via MEP, etc.) for our scholars.
- Graduate students in the Psychology program will conduct the research described in Section 9 of the proposal, under the guidance of Prof. Covarrubias. They will collect the data, analyze it, design further experiments as needed, and help with writing and presenting their findings for wide dissemination.