

Scaffolded Mentorship and Longitudinal Engagement Support High School Students' Progression to Research Contribution

David Siqi Liu

University of California, San Diego

Veronica Gomez-Godinez

University of California, San Diego

Linda Shi

zshi@ucsd.edu

University of California, San Diego

Research Article

Keywords: High School Research, Near-Peer Mentoring, Scaffolding, Science Identity, Longitudinal Engagement, Communities of Practice, STEM Persistence, Scalability, Research Productivity

Posted Date: September 10th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10670875/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.
[Read Full License](#)

Additional Declarations: No competing interests reported.

1 **Scaffolded Mentorship and Longitudinal Engagement Support High School Students'**
2 **Progression to Research Contribution**

3 David Siqi Liu, Veronica Gomez-Godinez, Linda Shi*

4 Institute of Engineering in Medicine, University of California San Diego

5 9500 Gilman Dr., SERF 295, MC 0435, La Jolla, CA, 92093, USA

6 *Corresponding Author: Linda Shi, zshi@ucsd.edu

7 **Keywords:** High School Research, Near-Peer Mentoring, Scaffolding, Science Identity,
8 Longitudinal Engagement, Communities of Practice, STEM Persistence, Scalability, Research
9 Productivity

10 **Abstract**

11 Early exposure to authentic research experiences has been shown to influence students'
12 persistence and identity in STEM. However, scaling such opportunities for high school students
13 within research-intensive environments remains challenging. This study examines the Outreach
14 Program for Advancing Learning in STEM (OPALS), a structured research program that
15 integrates a multi-tier mentorship model with a staged developmental framework and
16 longitudinal engagement.

17 Using program data collected from 2023 to 2026, we analyze participation patterns, retention,
18 and scholarly output across multiple cohorts. Participation increased substantially over the study
19 period, accompanied by higher rates of returning students and a marked rise in abstracts,
20 posters, and manuscripts. Students who engaged across multiple sessions were more likely to

1 contribute to research outputs, and mixed-experience groups demonstrated higher completion
2 rates than groups composed entirely of new participants.

3 These findings suggest that scaffolded mentorship and extended engagement may support
4 progression from initial exposure to active research contribution. The OPALS model provides a
5 potential framework for expanding access to authentic research experiences while maintaining
6 continuity and productivity within pre-college programs.

1 Introduction

2 Early participation in research is associated with increased persistence in STEM, improved self-
3 efficacy in scientific practice, and a stronger identification with scientific careers (**Chemers et**
4 **al., 2011**). While these benefits are well-documented for undergraduate populations (**Lopatto,**
5 **2007**), extending authentic research experiences to high school students involves unique
6 logistical and pedagogical challenges—particularly within research-intensive institutions where
7 the cognitive apprenticeship between faculty and novice learners is often difficult to bridge.

8 Traditional pre-college programs frequently emphasize short-term exposure or isolated skill
9 acquisition. Such models often lack the longitudinal continuity necessary for students to move
10 beyond peripheral participation (**Wenger, 1998**) and engage in the iterative, non-linear
11 processes of science, such as hypothesis refinement and troubleshooting. Without sustained
12 engagement, students may develop technical familiarity but fail to internalize the discursive
13 identity required for scholarly communication (**Brown et al., 2005**).

14 The Outreach Program for Advancing Learning in STEM (OPALS) was developed to address
15 these challenges through a scaffolded design (**Sawyer, 2005**). The program combines a multi-
16 tier mentorship structure with a staged research framework and integrates both short-term
17 intensive and longer-term hybrid formats. This design aims to support students as they move
18 from initial exposure toward more sustained participation in research.

19 This study examines the following questions:

- 20 1. How does a multi-tier mentorship structure support student engagement and continuity
21 across cohorts?
- 22 2. In what ways does a staged research framework facilitate progression toward
23 independent contribution?

1 3. Is longitudinal participation associated with increased retention and scholarly output?

2 By focusing on measurable outcomes such as participation patterns and research
3 dissemination, this study aims to contribute to the design of scalable pre-college research
4 programs.

5 **Methods**

6 **Program Context and Participants**

7 The OPALS program operates within the Institute of Engineering in Medicine at the University of
8 California, San Diego. The program has expanded significantly over time, supporting over 100
9 high school students annually in recent cohorts.

10 This study examines data collected mainly from five recent program cycles (2021–2026).
11 Participants were selected through an application process based on academic preparation,
12 interest in STEM, and willingness to engage in collaborative research. Returning students were
13 encouraged to continue participation across sessions.

14 **Program Design**

15 The program consists of two formats:

- 16 • A summer session, conducted as a four-week intensive research experience
- 17 • A spring session, conducted over approximately four months with hybrid participation

18 These formats are designed to complement one another, providing both initial immersion and
19 extended engagement. **Table 1** provides a comparative analysis of the logistical setup,
20 advantages, and limitations of the Spring and Summer session formats.

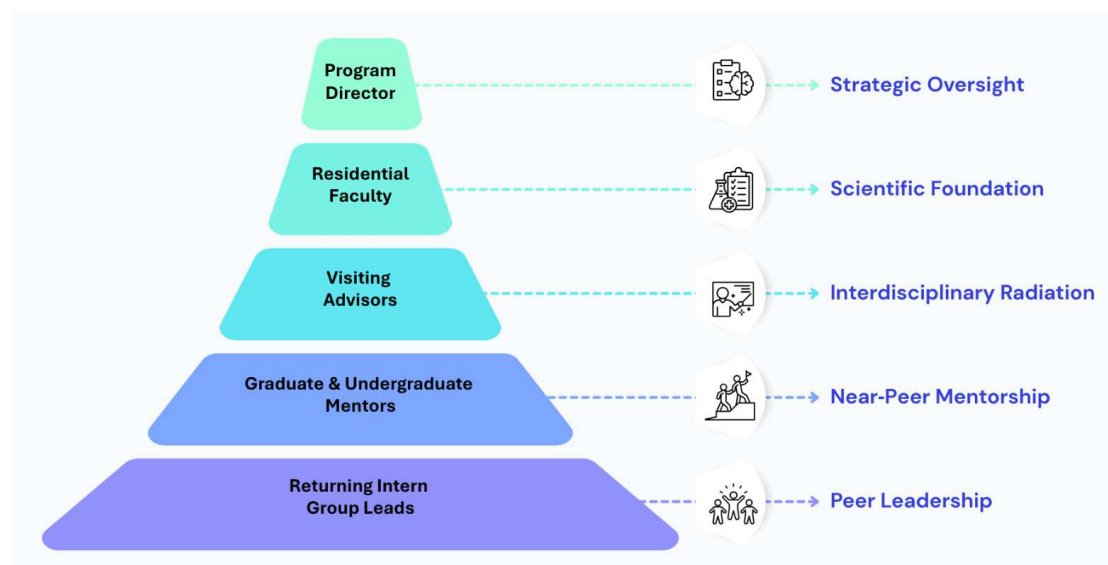
1 **Table 1** Comparison of OPALS Spring Session and Summer Session

Table 1 Comparison of OPALS Spring Session and Summer Session		
Category	Spring Session	Summer Session
Length	4 months (Jan–May)	4 weeks (July)
Format	Hybrid, extended	In person, intensive
Student Time Commitment	2–4 hrs per week	6–8 hrs per day
Engagement Frequency	Monthly in person gatherings; monthly presentations; weekly online mentor meetings; 3–5 lab tours over 1–2 days	Daily in person gatherings; weekly presentations; mentor meetings three times weekly; 3–5 lab tours on separate days
Advantages	Supports deeper scholarly development and sustained writing; allows extended data refinement; increases access for nonlocal and international students	Provides immersive research intensity and strong social cohesion; enables focused work without school distractions; offers an authentic day in the life experience
Limitations	Requires balancing research with school; less immersive than daily campus life; limited wet lab time due to remote components	Steep learning curve in a short window; limited time for reflection or iterative writing; restricted to students able to commute to San Diego

2 **Mentorship Structure**

3 The program employs a multi-tier mentorship model that includes program director, faculty
4 oversight, visiting advisors, near-peer mentors, and returning student group leads. As illustrated
5 in **Figure 1**, this structure distributes mentorship responsibilities and allows students to receive
6 both technical and conceptual support at multiple levels. On average OPALS research team has

1 9.56 persons.



2

3 **Figure 1. 5-tier Mentorship Structure**

4 Tier 1: Program Director

5 The Program Director serves as the program’s architect, balancing logistics, recruitment, and
6 long-term planning. The Director also connects students to the broader STEM ecosystem by
7 organizing lab tours, coordinating industry partnerships, and hosting guest speakers who
8 contextualize students’ research within real-world applications.

9 Tier 2: Residential Faculty

10 Three Residential Scientists in Biophotonics and Neuroscience anchor the program’s intellectual
11 core. They maintain methodological standards, ensure disciplinary depth, and provide continuity
12 across sessions.

13 Tier 3: Visiting Advisors

Visiting Advisors—drawn from industry and academia—extend core biophotonics themes into fields such as environmental science, oncology, and sustainable engineering. Their expertise keeps projects aligned with current scientific frontiers. In the latest session, of 24 projects, 10 were led by residential faculty, 5 were co-advised, and 9 were directed by visiting experts.

Tier 4: Graduate & Undergraduate Mentors

University-level mentors provide day-to-day technical guidance, translating complex concepts into accessible steps. Their near-peer role has been shown to strengthen students' STEM identity and confidence (Tenner et al., 2007).

Tier 5: Returning Intern Group Leads

Returning interns serve as group leads, managing project logistics, documenting progress, and submitting bi-weekly reports to the Program Director. This role cultivates leadership, accountability, and the organizational skills required for advanced research.

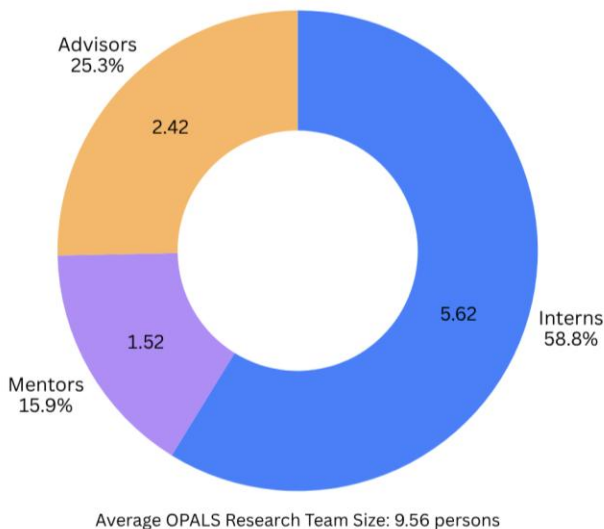


Figure 2. Average composition of OPALS Research Teams

Figure 2 shows the average composition of OPALS research teams. This structure functions as a community of practice (**Wenger, 1998**), where knowledge is shared across varying levels of expertise.

Developmental Framework

The OPALS intern experience follows a five stage developmental sequence that reflects the authentic lifecycle of a scientific investigation as illustrated in **Figure 3**. This framework provides scaffolded support, a temporary structure that is gradually removed as students gain autonomy, to build the cognitive, analytical, and technical competencies necessary for independent research (**Sawyer, 2005**).

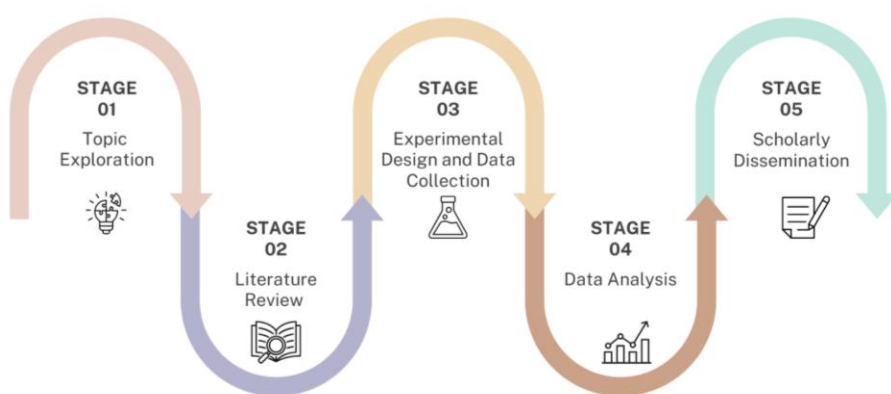


Figure 3. Five Stage Developmental Framework

Stage 1: Topic Exploration

Students begin by aligning their interests with laboratory research clusters. Through an independent exploration phase, they investigate their assigned topic, develop an early conceptual model, and share their initial understanding with the community. This stage centers student agency and encourages personal ownership of the scientific problem.

1 Stage 2: Literature Review

2 Interns then engage in structured scholarly reading. With guidance from mentors, they analyze
3 foundational and current peer reviewed studies. During the second milestone gathering,
4 students present an integrated review of the literature and participate in a defense style
5 discussion that deepens their understanding of core biological and engineering principles.

6 Stage 3: Experimental Design and Data Collection

7 Students enter the experimental phase, working closely with mentors to design procedures,
8 collect data, and conduct early analyses. This stage intentionally emphasizes a pedagogy of
9 failure, where students must articulate obstacles and troubleshooting strategies. This reframes
10 experimental setbacks as necessary productive struggles that are foundational to the iterative
11 nature of science (**Simpson and Maltese, 2017**).

12 Stage 4: Data Analysis

13 As experiments stabilize, interns refine methods, resolve anomalies, and transform raw data
14 into publication quality visualizations. They practice scientific storytelling by developing a
15 coherent interpretive narrative that connects their quantitative results to broader scientific
16 questions.

17 Stage 5: Scholarly Dissemination

18 In the final stage, interns integrate their full project into abstracts, posters, and oral
19 presentations suitable for professional conferences and technical forums. By preparing
20 manuscripts and presenting to external audiences, they solidify their scholarly identity and enter
21 the scientific community as emerging contributors (**Brown et al., 2005**).

22 Each stage includes defined milestones and feedback to support iterative learning.

Results

Program data were compiled from institutional records, including participation, retention, and research output. Descriptive analyses were conducted to examine trends across cohorts and program formats.

Program Growth and Participation

Throughout the five-year study period (2020–2025), the OPALS program transitioned from a focused pilot initiative into a high-capacity research pipeline. This expansion is characterized by a significant increase in cohort sizes, reflecting both the scalability of the mentorship model and an intensifying demand for accessible STEM research opportunities. While the 2021–2022 sessions established a baseline of steady foundational growth, the subsequent years marked a shift toward exponential scaling as shown in **Figure 4**.

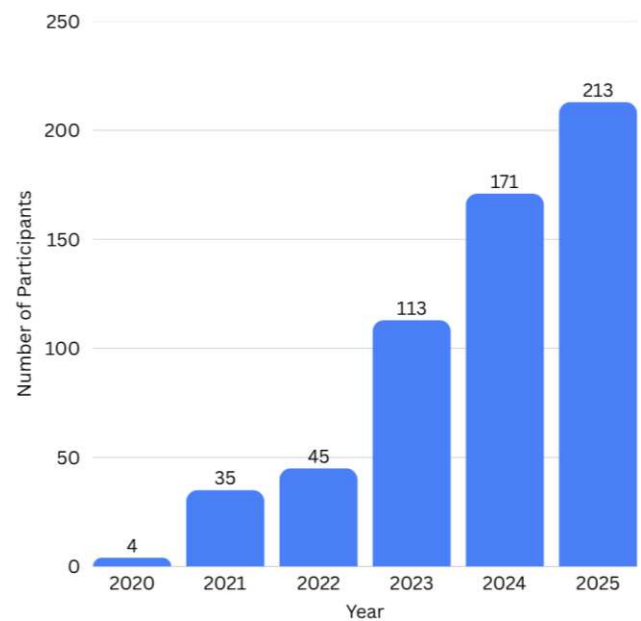


Figure 4. OPALS program participation in 2020-2025.

Furthermore, **Figure 5** highlights a phenomenal growth in geographic diversity. While non-local students comprised only 21% of the Summer 2023 cohort, this figure climbed to over 31% by Summer 2025 and reached 41% in the Spring 2026 session. This aggressive growth indicates that the Collaborative Support Model and remote-friendly format are effective at engaging students across geographic boundaries. The data also suggests that the four-month Spring session is becoming increasingly more popular than the compact four-week Summer session. The extended timeline allows interns to engage more deeply with background research, explore new methods at a sustainable pace, manage complex data collection, and refine their results into conference ready abstracts.

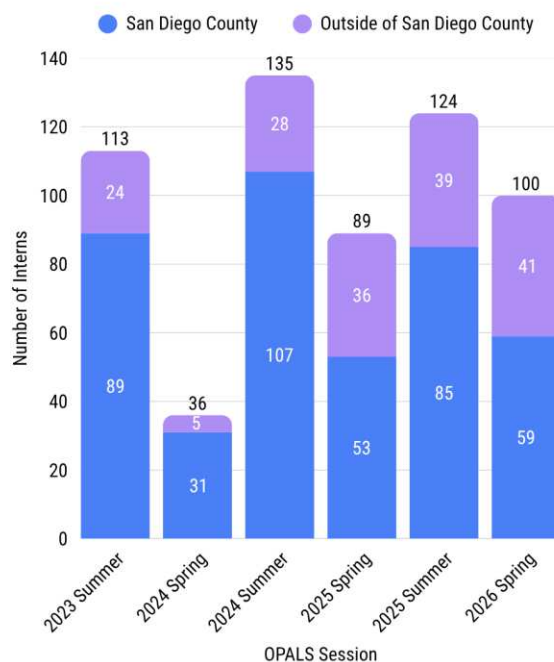


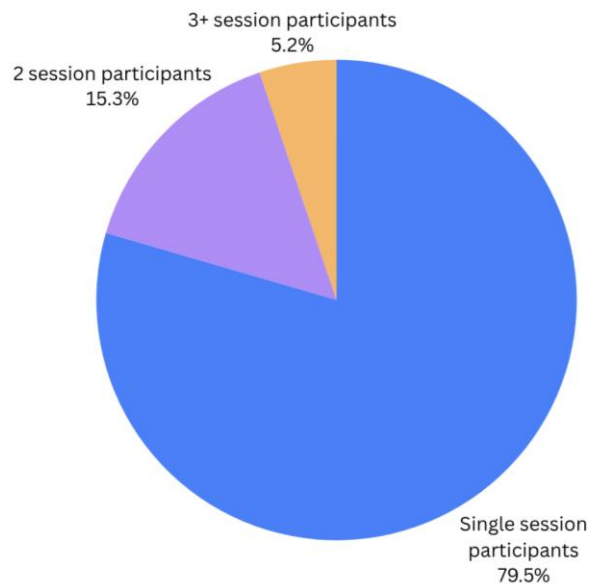
Figure 5. OPALS participation by session and geographic distribution (2023-2026)

Retention and the Sustained Engagement

A major driver of OPALS program success is the sustained engagement of interns across multiple terms. Although each cycle brings in many new students, those who return for

1 additional sessions show far stronger persistence in advanced research activities. Retention is
2 especially high among interns who complete consecutive spring and summer terms, indicating
3 that a dual session pathway provides the continuity needed to master research practices and
4 take on leadership roles.

5 **Figure 6** shows about 79.5% of interns complete one session, while a focused core of 20.5%
6 returns for additional sessions. This returning cohort has an outsized impact. These veteran
7 interns provide peer leadership, accelerate onboarding for new students, and maintain
8 continuity for multi-session projects.



9
10 **Figure 6.** Distribution of total number of sessions participation (2020-2025)

11 This retention creates a clear learning curve advantage. As illustrated in **Figure 7**, while single-
12 session participants establish a strong foundational output of 1.15 publications per session,
13 productivity surges to 1.50 for those returning for a second term, ultimately peaking at 1.62 for
14 students with three or more sessions. This represents a 41% total increase in research
15 productivity driven by cumulative experience.

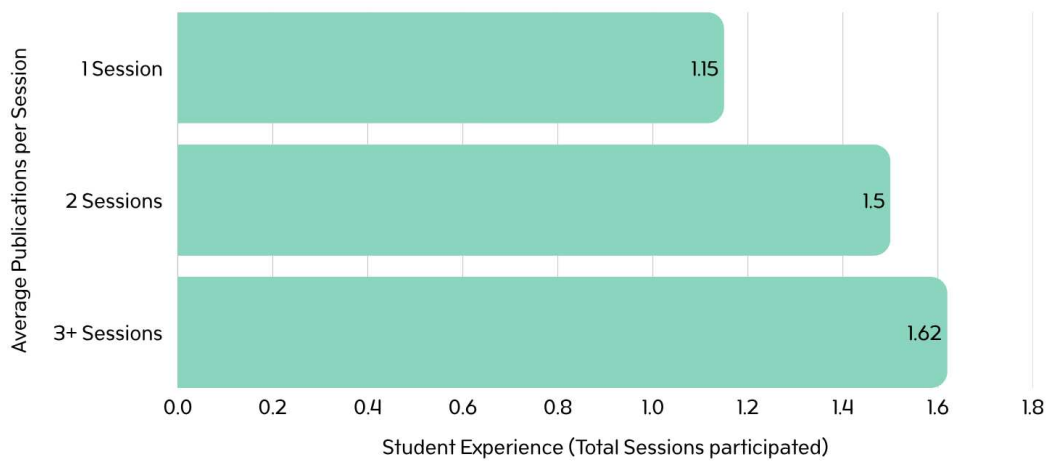


Figure 7. Research productivity: average publications per session.

Scholarly Output

The OPALS program has rapidly expanded from a pilot initiative into a mature research pipeline, marked by a sharp rise in total scholarly output. As shown in **Figure 8**, publications increased from 4 in 2021 to 76 in 2025, reflecting the establishment of a stable institutional structure and a growing participant cohort. This acceleration aligns with the program's standardized research framework, which enabled consistent productivity across multiple STEM domains.

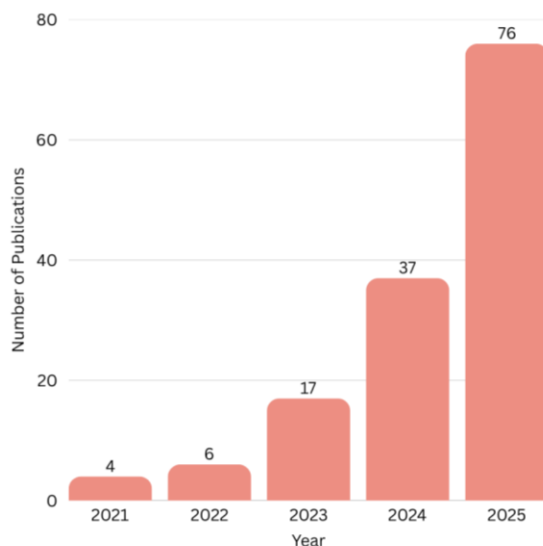


Figure 8. Exponential growth in OPALS research publication (2021~2025).

A parallel increase in individual productivity underscores the program's strengthening research capacity. **Figure 9** demonstrates a steady rise in average publications per intern from 2021 to 2024, followed by a pronounced jump in 2025. This pattern reflects the experience dividend contributed by returning multi-session students, whose accumulated expertise enhances team performance. By maintaining a stable publication-per-student ratio while scaling enrollment, OPALS shows that its mentorship model can support high-volume, peer-reviewed output without compromising quality.

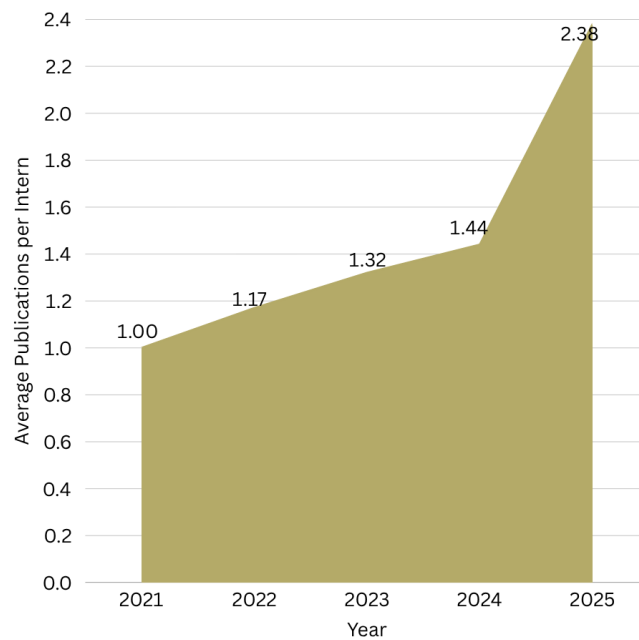


Figure 9. Rising Average Publications per Intern (2021–2025)

The program's disciplinary footprint broadened substantially as its research ecosystem matured. **Figure 10** illustrates the shift from early concentration in Biophotonics and Cellular Signaling to a balanced distribution across Neuroscience, Biomaterials, and computational modeling by 2025. With 76 publications spanning all five domains, OPALS reached a state of inclusive excellence, demonstrating that its mentorship structure can scale disciplinary breadth while preserving depth in each research area.

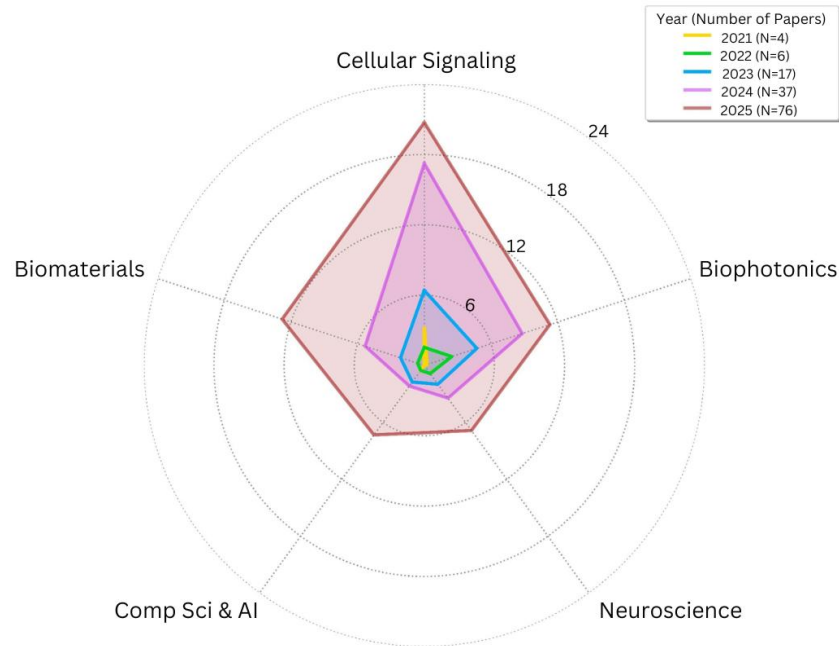


Figure 10. Expansion of OPALS Research Activity Across Disciplines (2021–2025)

Discussion

The findings suggest that a structured research environment combining staged progression and distributed mentorship can support meaningful engagement among high school students.

Students who participated across multiple sessions were more likely to contribute to research outputs, indicating a shift from initial participation to more active involvement.

The longitudinal structure of the program appears to play an important role in this progression.

Extended engagement allows students to revisit concepts, refine their work, and develop a greater sense of ownership over their projects.

The mentorship model also contributes to scalability. By incorporating near-peer mentors and returning students, the program creates internal support systems that reduce reliance on faculty while maintaining continuity across cohorts.

1 These patterns can be understood as part of a broader research ecosystem, in which
2 experience accumulates across participants and over time. Rather than functioning as isolated
3 cohorts, the program operates as a connected system where prior participants contribute to
4 future outcomes.

5 **Limitations**

6 This study relies on program-level data and does not include controlled comparisons. As a
7 result, causal relationships cannot be definitively established. Additionally, outcomes may be
8 influenced by self-selection, as students who continue participation may differ from those who
9 do not.

10 Future studies could incorporate survey-based measures and comparative designs to further
11 evaluate the impact of program structure.

12 **Conclusion**

13 This study suggests that scaffolded mentorship, staged research progression, and longitudinal
14 engagement may support high school students in moving from initial exposure to active
15 participation in research. The OPALS model provides one approach to expanding access to
16 authentic research experiences while maintaining continuity and productivity at scale.

17 **Funding statement**

18 This work was supported by a generous gift from Beckman Laser Institute Inc. to Dr. Linda Shi.
19 The first author participated in the UCSD IEM OPALS internship program. We gratefully
20 acknowledge the support of Leighton Foundation, Ming-Wei Wu, Shu Chien, Lizhu Chen (CorDx
21 Inc.), Xinhua Zheng, David & Leslie Lee, Mingwei He & Wen Shi.

22

23

Ethics Approval, Consent to Participate, and Consent to Publish declarations:

This study was approved by the Institutional Ethics Committee of the University of California, San Diego. The study was conducted in accordance with the Declaration of the ethical standards of the Institutional Review Board (IRB) of the University of California, San Diego (Protocol #809418), Informed consent was obtained from all participants and their legal guardians.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

1. Lopatto, D. (2007). Undergraduate research experiences support science career decisions and active learning. **CBE-Life Sciences Education**, 6(4), 297–306.
<https://doi.org/10.1187/cbe.07-06-0039>
2. Chemers, M. T., Zurbriggen, E. L., Syed, M., Goza, B. K., & Bearman, S. (2011). The Role of Efficacy and Identity in Science Career Commitment Among Underrepresented Minority Students. **Journal of Social Issues**, 67(3), 469–491.
<https://doi.org/10.1111/j.1540-4560.2011.01710.x>
3. Auchincloss, L. C., Laursen, S. L., Branchaw, J. L., Eagan, K., Graham, M., et al. (2014). Assessment of Course-Based Undergraduate Research Experiences: A Meeting Report. **CBE-Life Sciences Education**, 13(1), 29–40. <https://doi.org/10.1187/cbe.14-01-0004>
4. Zaniewski, A. M., & Reinholz, D. (2016). Increasing STEM success: a near-peer mentoring program in the physical sciences. **International Journal of STEM Education**, 3(1), 14. <https://doi.org/10.1186/s40594-016-0043-2>

- 1 5. Sawyer, R. K. (Ed.). (2005). **The Cambridge Handbook of the Learning Sciences**.
2 Cambridge University Press. <https://doi.org/10.1017/CBO9780511816833>
- 3 6. Simpson, A., & Maltese, A. (2017). "Failure is a part of make": A study of how students
4 grapple with failure and persistence in making. **International Journal of STEM**
5 **Education**, 4(1), 1–15. <https://doi.org/10.1186/s40594-017-0057-4>
- 6 7. Brown, B. A., Reveles, J. M., & Kelly, G. J. (2005). Scientific literacy and discursive
7 identity: A theoretical framework for understanding science learning. **Science**
8 **Education**, 89(5), 779–802. <https://doi.org/10.1002/sce.20069>
- 9 8. Wenger, E. (1998). **Communities of Practice: Learning, Meaning, and Identity**.
10 Cambridge University Press. <https://doi.org/10.1017/CBO9780511803932>
- 11 9. Malhi, I., Liu, Z., Wu, C., Gomez-Godinez, V., Shi, L. (2025). Exploring student
12 perceptions of diversified teaching methods: A case study of the UCSD IEM OPALS
13 program. **Journal of STEM Outreach** 8(1).
- 14 10. Wang, Z., Gomez-Godinez, V., Wu, C., Shi, L. Z. (2025). Empowering future scientists:
15 The UCSD OPALS program's impact on high school students in STEM. **Biomedical**
16 **Engineering Education** 5. <https://doi.org/10.1007/s43683-025-00209-2>