Qualitative Findings from Study of Interdisciplinary Education in Computational Modeling for Life Sciences Student Researchers from Emerging Research Institutions

Aasakiran Madamanchi
Department of Agricultural & Biological Engineering
Purdue University
West Lafayette, Indiana, USA
Email: amadaman@purdue.edu

Shenika V. Poindexter
Department of Biology
Xavier University of Louisiana
New Orleans, Lousiana, USA
Email: spoindex@xula.edu

Monica E. Cardella
School of Engineering Education
Purdue University
West Lafayette, Indiana, USA
Email: mcardell@purdue.edu

James A. Glazier
Department of Intelligent Systems Engineering
Biocomplexity Institute
Indiana University
Bloomington, Indiana, USA
Email: glazier@indiana.edu

David M. Umulis
Department of Agricultural & Biological Engineering
Purdue University
West Lafayette, Indiana, USA
Email: dumulis@purdue.edu

Abstract—**This Work-in-Progress paper in the Research Category explores the unique challenges and opportunities of interdisciplinary education in computational modeling for life sciences student researchers at emerging research institutions (*ERIs*), specifically in predominantly undergraduate institutions (*PUIs*), and minority serving institutions (*MSIs*). Engineering approaches such as computational modeling have underappreciated potential for capacity building for the biomedical research enterprises of ERIs. We perform a bibliometric analysis to assess the prevailing use of computational modeling in life sciences research at MSIs, and PUIs. Additionally, we apply Social and Cognitive Theory to identify unique attitudinal, social and structural barriers for student researchers in learning and using computational modeling approaches at each of these types of institutions. Specifically, we use quantitative retrospective pre- and post-survey data and qualitative interviews of students who have attended a short-format computational modeling training course. We supplement these data with qualitative interviews of the students' faculty sponsors. Upon completion, this study will provide deeper understanding of issues related to computer science and engineering education at non-Research I institutions.**

Primary Topic— 2018 Thematic Track: diversity / equity / inclusion in engineering/computing. Secondary Topics: Approaches to Interdisciplinary Education; Engineering Education Research; Discipline Specific Issues: Bioengineering and/or Biomedical Engineering)

I. Introduction

In the United States, almost one-third of institutions of higher education conduct under $15M annually in federally-sponsored research and thus qualify as emerging research institutions (ERIs) [1]. ERIs are diverse, including predominantly undergraduate institutions (PUIs), and minority-serving institutions (MSIs), but have similar limitations in research resources [1]. These institutions play a critical role in producing the STEM workforce in the U.S.A., as they educate approximately one-third of the total student population, and a substantial portion of the minority student population [2]. Over a fifth of STEM doctorates and over half of STEM masters degrees in the United States are awarded outside of Carnegie-designated Research I (RI) universities [3]. PUIs train a large number of future life sciences doctorates [4]. MSIs broaden participation in life sciences research, educating a majority of black life sciences doctorates [5]. None of our interview subjects came from the two American MSIs which fall between the national academy ERI designation and the Carnegie RI designation, so all MSI institutions in this document are also ERIs.

As the life sciences become increasingly data-intensive, life sciences students increasingly need interdisciplinary education in engineering approaches such as computational modeling [6, 7]. Many RI universities have made substantial investments in computational and systems-biology education [8]. However, research on interdisciplinary engineering education for life sciences students from less-resourced PUIs and MSIs is limited. Published reports suggest that research experience is critical for persistence in STEM fields at PUIs [9]. Many reports discuss research capacity building strategies for ERIs, including PUIs and MSIs [10, 11]. However, to our knowledge, no studies address the prevalence of computational modeling in life sciences research at PUIs, MSIs or ERIs in

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general, or the specific challenges to interdisciplinary education of student researchers from those institutions. A deeper understanding of these issues could improve the research capacity of ERIs and broaden participation in computational modeling. This Work-in-Progress paper reports our research approach and preliminary results on these problems.

II. Theoretical Framework & Research Questions

A. *Theoretical Framework*

This study applies Bandura's Social cognitive theory (SCT), a theory of human behavior that emphasizes the interaction between individuals and their environment in determining behavior [12]. SCT's focus on both individual and structural elements of learning aligns with our interest in understanding the role of institutional environments in modulating how life science students learn and use computational modeling. Studies of diversity in higher education and of minority persistence in STEM have successfully applied SCT [13, 14].

B. *Research Questions*

This study is to address the following research questions:

- *To what extent do PUIs and MSIs currently utilize computational modeling in life sciences research, and how does their level of usage compare to RI universities?*
- *What are the unique challenges and affordances for life sciences student researchers from PUIs and MSIs in learning and using computational modeling?*
- *Do life sciences student researchers from PUIs and MSIs show improvement in self-efficacy in modeling and self-concept as a scientist after participation in the CompuCell3D User Training Workshop?*

III. Methods

A. *Research Context*

In this study we collaborated with the developers of CompuCell3D (CC3D), an NIH and NSF-funded flexible scriptable modeling environment designed to lower technical barriers for life scientists wishing to develop computational models [15,16]. For the past thirteen years the CC3D developer team has hosted an annual short-format 'workshop' providing computational modeling training to life-sciences students and faculty from around the world. The CC3D modeling environment is appropriate for our study because it has been used for cutting-edge research published in the highest impact life-sciences journals, but is suitable for low-resource research environments, as it is lightweight enough to run on consumer-grade laptops or desktops [16]. Past workshops have included a substantial number of researchers from low-resource research institutions abroad (~18% of workshop participants come from research institutions in low or middle-income nations). Building on that success, the CC3D developer team is currently engaged in a new effort to recruit workshop participants from MSIs and PUIs. This recruitment effort has also provided our data sampling.

B. *Data Collection & Analysis*

The data collected for this study include: (1) Bibliometric analyses of academic publication and federal research funding, (2) quantitative retrospective pre- and post- workshop surveys, and (3) qualitative semi-structured interviews of workshop attendees and their faculty sponsors.

For analysis, semi-structured interviews were audio – recorded, transcribed and then coded using the 'long table method.' We then correlated emergent themes with our research questions.

IV. Preliminary Findings

This Work-in-Progress paper presents preliminary results from our qualitative interviews with the faculty sponsors of potential workshop attendees.

A. *PUIs*

Interviews with faculty sponsors from PUIs have produced several emergent themes.

1) *Theme I: Student Time Constraints*

A major theme in interviews with PUI faculty was the unique time constraints on research at PUIs. Many labs at PUIs rely heavily on undergraduate researchers who have limited time to devote to their research projects. Most student research happens during a limited summer period, therefore the 'steeper learning curve' perceived for computational modeling was a concern for many faculty. One professor stated "I can teach a student to do tissue culture and Q (qRT-PCR) in an afternoon and the student has results to think scientifically about, immediately. The workshop takes a week of technical training and they still might not be at that stage."

Concern about constraints on student time also manifested as uncertainty over how to break modeling research into subprojects. One participant stated "I generally have students for only a year. That's two semesters for independent study and then one summer. I have a responsibility to make sure that students have something very concrete that they take away from that experience." Others noted that they weren't sure how more than one student could work on the same modeling project at the same time. Modeling was often contrasted to wet-lab experiments in which individual student work was often interchangeable. Additionally, many faculty relied on more experienced students to help newer students learn wet-lab techniques; they were unsure whether this mode of transmission of lab skills was possible with modeling.

At the same time, some faculty perceived the potential for computational modeling to help their research program overcome constraints on student time. They anticipated that computational modeling could allow for remote or intermittent student participation, lowering the barrier to research involvement for students with jobs or other commitments. One interviewee suggested that modeling could allow him to engage more students than his lab facility currently allows.

2) Theme II: Faculty Development

In addition to aforementioned constraints related to student time, many faculty described limitations in faculty development time. Many noted their greater teaching loads compared to RI faculty and that they had limited time to learn new technologies. They suggested that an obstacle to offering computational modeling opportunities to their students was the requirement that they would need to learn a lot about computational modeling to be able to understand how to create mini-projects for students and to mediate hand-offs between students.

Others observed that computational methods were an area of need for their particular campus. As one professor stated, "we don't have engineering here, we do have a computer science department but it's literally three people. Nobody in my department has this expertise and there is nobody here on campus we can go to." Another faculty member commented, "I just know that if I do this, everyone is gonna come out of the wood work to ask me for help. It's already like that with simple office computer stuff". These faculty members all observed that the faculty development opportunities on their campus were typically focused towards improving their teaching.

3) Theme III: Student Interest in Modeling

A third theme was perceived student interest. Many interviewees anticipated that students would be interested in learning computational modeling because of its perception as 'high tech.' They noted that the animations and videos of models built on the CC3D platform could potentially interest students. One interviewee observed,

> *"One thing I've noticed in the past is that microscopy images can really have that 'wow factor' that makes some students feel that they are doing real science and gets them to really buy in. I could definitely see computational modeling having that same effect."*

Some participants anticipated that the involvement of computer programming could attract a wider range of students due to the broader applicability of coding skills after graduation. However, other interviewees expected that some of their students would be intimidated by computational modeling. These faculty drew on prior experience instructing undergraduate researchers in math-intensive lab skills such as statistical significance testing, or the calculation of serial dilutions. They suggested that some students may have chosen biology as opposed to computer science or engineering, because they are less interested in or comfortable with math,

> *"A concern that I have is that is, if I start featuring something rather technologically intensive like modeling – am I going to be scaring some intimidating some students and keep them from getting involved. The students who come here don't always think of themselves as a STEM person. A lot of them came to Y because it's not a Georgia Tech. A priority for me, is demystifying science, and I have to really consider whether this type of simulation work runs counter to that goal"*

B. MSIs

Analysis of interviews with faculty sponsors from MSIs have revealed several preliminary themes.

1) Theme I: Research Niche

One frequent theme in interviews with MSI faculty was the importance of maintaining a fit with the research niche of their institutions. Interviewees believed that life sciences research at MSIs is more applied and at times more deeply rooted in physiology than at some RI institutions. These participants were adamant that a key to research success at an MSI was in "specializing in solid science that isn't being done in other places." Some perceived tension between applied and systems approaches to life sciences. For these scientists, the description of computational modeling as 'virtual tissue simulation' eased these tensions by expanding their understanding of the role of computational modeling. Other faculty considered adherence to their research niche to be a reason to collaborate with computational modeling groups rather than developing computational models directly. One interviewee observed, "I'm not a systems biologist, and at this point I'm not going to be a systems biologist. I do see the value in it though so a collaboration is something I would explore."

2) Theme II: Computational Modeling vs. Bioinformatics

Several interviewees independently related that they had already integrated bioinformatics into their research or had previously considered doing so, suggesting that they saw computational modeling and bioinformatics analyses as similar or competing approaches in life sciences research. For these faculty, the clear connection between bioinformatics and health disparities was seen as furthering the institutional mission of their universities. No interviewees perceived a connection between computational modeling and health disparities. Several faculty noted that the bioinformatics research community has done much more to reach out to MSIs with tools and training, as seen in the following quotes:

> "*You know we get invitations to collaborate on SNP stuff all the time, but this is the first time anyone involved with modeling has ever gotten in touch with us"*

> *"At first I thought you were with the Bioinformatics group at [local university], we work with them quite extensively."*

3) Theme III: Student Interest in Modeling

Just as in our interviews with PUI faculty, many MSI interviewees observed that their students were "digital natives" and highly proficient in technology, so they anticipated that their students would be interested in computational modeling.

Several interviewees suggested that computational modeling was perceived as 'prestigious' or 'cutting edge.'

These interviewees hoped computational modelling would help raise the impact of their current work or help their students attain more high-profile postdoctoral appointments after graduation. Many interviewees viewed exposure to interdisciplinary education in computational modeling to be important for their students' development. They viewed this experience as a part of training their students for future life-sciences research, and several interviewees indicated that resources for interdisciplinary training in these areas was insufficient at their home institutions.

Interestingly, MSI interviewees reported less perceived interest in coding as a transferable job skill than the PUI cohort. In fact, the primary perceived motivation for students' interest in modeling was to answer research questions that were not amenable to wet-lab biology. Pragmatic career-related concerns were secondary to more idealistic 'scientific' questions.

V. Discussion & Future Directions

This Work-in-Progress paper is our first step in a larger effort to understand how to best support student researchers from PUIs and MSIs in learning and using interdisciplinary engineering approaches, such as computational modeling. Identifying the challenges facing non-engineering STEM students in learning computational modeling helps us in thinking about how we teach first year engineers as well as biomedical and biological engineers. In future work, to complement our findings on student researchers, we hope to specifically investigate interdisciplinary education in engineering approaches within the life sciences curricula at PUIs and MSIs. The preliminary qualitative findings in this paper provide a faculty perspective on the challenges and affordances for interdisciplinary education in computational modeling for life sciences student researchers from PUIs and MSIs. Non-engineering faculty from STEM disciplines are often key stakeholders in implementing integrated STEM curricula; understanding their perspectives on using a core engineering approach such as computational modeling provides valuable insight for working with similar faculty in educational contexts.

Consistent with Social cognitive theory, the interview responses aligned with both structural (e.g. time constraints) and personal (i.e. personal interests) aspects of learning. This fall, upon completion of the 2018 training workshop for CC3D users, we will be able to complement these data with the insights of student researchers. Our quantitative surveys and bibliometric analysis will extend these findings. For example, our survey data will investigate whether faculty perceptions that computational modeling provides 'prestige' or a 'wow factor' translate into post-workshop increases in student self-concept as scientists or modelers. Our survey data will also allow us to further connect our work to Social cognitive theory as we investigate self-efficacy and self-concept through Likert scale survey items. The bibliometric analysis will provide information about whether the structural elements we identify through our qualitative work are representative of PUIs and MSIs across the nation.

Important limitations of our study may affect the generalizability of our results. The faculty sponsors that we interview are self-selected respondents to the outreach campaign of the CC3D modeling workshop. This population may be more receptive or positive towards computational modeling than other faculty. Limitations in sample size preclude study of differential effects among different demographic subgroups. Emphasizing technology in education can sometimes deepen inequality; future work will need to grapple with these issues [17].

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References

[1] National Academy of Engineering and National Research Council. 2009. *Partnerships for Emerging Research Institutions: Report of a Workshop.* Washington, DC: The National Academies Press. https://doi.org/10.17226/12577.

[2] E. Psalmonds, "Retooling Emerging Research Institutions," National Council of Undergraduate Research Administrators, vol. XLI, no. 2, pp. 12–13, 2009.

[3] National Science Board. Science and Engineering Indicators 2016. Arlington: National Science Foundation, 2016

[4] R. D. Slocum, J. D. Scholl. "NSF Support of Research at Predominantly Undergraduate Institutions (PUIs)." *Council on Undergraduate Research Quarterly*, vol. 34, no. 1, pp. 31-40, 2013

[5] V. C. Lundy-Wagner, "Coming Out of the Shadows: Rethinking the Education Policy Agenda for Diversity and HBCUs," *New Directions for Higher Education*, vol. 2015, no. 170, pp. 91–101, 2015.

[6] National Research Council (U.S.)., Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond. Washington, D.C.: National Academies Press, 2014.

[7] A. Arnold and M. Greer, "Convergence: a transformative approach to advanced research at the intersection of life, physical sciences and engineering and enhanced university-industry partnerships," *Journal of Translational Science*, vol. 1, no. 3, 2016.

[8] P. Sharp and S. Hockfield, "Convergence: The future of health," *Science*, vol. 355, no. 6325, Sep. 2017.

[9] M. J. Graham, J. Frederick, A. Byars-Winston, A.-B. Hunter, and J. Handelsman, "Increasing Persistence of College Students in STEM," *Science*, vol. 341, no. 6153, pp. 1455–1456, 2013.

[10] M. L. Kovarik, "Analytical chemistry research at primarily undergraduate institutions: training tomorrows investigators," *Analytical Methods*, vol. 7, no. 17, pp. 6960–6966, 2015.

[11] M. Gasman and F. Commodore, "The state of research on historically Black colleges and universities," *Journal for Multicultural Education*, vol. 8, no. 2, pp. 89–111, Mar. 2014.

[12] Bandura, A., "Social Foundations of Thought and Action: A Social Cognitive Theory", Prentice Hall, Englewood Cliffs, NJ, 1986.

[13] R. W. Lent, M. J. Miller, P. E. Smith, B. A. Watford, K. Hui, R. H. Lim, "Social cognitive model of adjustment to engineering majors: Longitudinal test across gender and race/ethnicity", *Journal of Vocational Behavior*, vol. 86, pp. 77-85, 2015.

[14] J. M. Trenor, S. L. Yu, C. L. Waight, K. S. Zerda, and T.-L. Sha, "The Relations of Ethnicity to Female Engineering Students Educational Experiences and College and Career Plans in an Ethnically Diverse Learning Environment," *Journal of Engineering Education*, vol. 97, no. 4, pp. 449–465, 2008.

[15] M. H. Swat, S. D. Hester, A. I. Balter, R. W. Heiland, B. L. Zaitlen, and J. A. Glazier, "Multicell Simulations of Development and Disease Using

the CompuCell3D Simulation Environment," *Methods in Molecular Biology Systems Biology*, pp. 361–428, 2009.
[16] M. H. Swat, G. L. Thomas, J. M. Belmonte, A. Shirinifard, D. Hmeljak, and J. A. Glazier, "Multi-Scale Modeling of Tissues Using CompuCell3D," *Methods in Cell Biology Computational Methods in Cell Biology*, pp. 325–366, 2012.
[17] I. Literat, "Implications of massive open online courses for higher education: mitigating or reifying educational inequities?," *Higher Education Research & Development*, vol. 34, no. 6, pp. 1164–1177, 2015.