American Association of Physics Teachers (AAPT)

White Paper for the AAPT Board of Directors and the National Science Foundation on Potential Funding Initiatives and Priorities

Endorsed by AAPT Board of Directors on April 10, 2021

Ernest Behringer[1], Dwain Debian[2], Elizabeth George[1], Alexis Knaub[3], Joseph Kozminski[1], Marie Lopez del Puerto[1], Kristine Lui[2], and Arlene Modeste Knowles[3]

The purpose of this white paper is to propose one new funding initiative to the National Science Foundation and three critical new funding priorities for the physics community that are appropriate for current or revised NSF solicitations.

NEW FUNDING INITIATIVE

(1) MODERNIZING INSTRUCTIONAL PHYSICS LABORATORIES WITH COMPUTATION

Provide funding for modernizing instructional physics laboratories to focus on developing transferable skills. Funding is needed to support developing new experiments, adapting effective experiments, and integrating computational elements through data acquisition, analysis, and modeling, leading to critical skill development of physics majors. This is an urgent need at two- and four-year colleges, universities, and technical institutions.

[1] Current and previous members of the Committee on Physics in Undergraduate Education.
[2] Previous members of the Committee on Physics at Two-Year Colleges
[3] Current members of the Committee on Diversity in Physics

FUNDING PRIORITIES

(2) PHYSICS CURRICULUM CONFERENCES

Provide funding for convening a set of physics curriculum conferences that deliver recommendations for innovative undergraduate physics curricula and pedagogy that prepare diverse students at two- and four-year colleges, universities, and technical institutions for the twenty-first century STEM workforce.

(3) PREPARING PHYSICS AND ASTRONOMY DIVERSITY CHANGE AGENT TEAMS FOR SUCCESS

Provide funding for supporting physics and astronomy departmental Equity, Diversity, and Inclusion (EDI) change agent teams whose primary function is to address and redress systemic EDI issues within physics and astronomy departments and to ensure that teams are appropriately trained to effectively undertake research-based interventions to improve physics and astronomy.

(4) CREATION OF A NATIONAL INSTITUTE FOR TWO-YEAR COLLEGE PHYSICS

Provide funding to create a national, virtual institute for two-year college physics that provides sustainable faculty training on updated curricula and pedagogies, continuing professional development, guidelines and critical space for community building, engagement, and sharing of resources.

The rationales for the funding initiative and priorities follow.

NEW FUNDING INITIATIVE

(1) MODERNIZING INSTRUCTIONAL PHYSICS LABORATORIES WITH COMPUTATION

The instructional physics lab community needs a replacement for the long-past Improving Laboratory Instruction (ILI) program. The rationale for this begins with the recognition that advances in science and technology involve the development of models to explain observed phenomena, predict new phenomena, and invent new materials and processes. The undergraduate physics laboratory curriculum provides crucial opportunities for careful observations of phenomena, for the development of essential skills, and for learning new techniques on which these advances are based. Laboratory experiments and projects also allow for integrating computational elements through data acquisition, analysis, and modeling. Experimentation therefore plays a fundamental role in increasing scientific understanding and improving technology. Physics students, who typically choose scientific and/or technical career paths, therefore need to develop experimental physics skills and concomitant skills in computational physics, communication, project management, and other transferable skills. The development of these valuable skills requires continual replacement and updating of laboratory experiments and associated equipment.

The proposed program would balance support for innovative, low-cost, high-accessibility labs with support for labs inspired by contemporary research. Such a balance can enable students from a variety of backgrounds, and situated in different environments, to develop needed lab skills. We recognize that some pathways to developing experimental skills (e.g., undergraduate research) are not available at some institutions due to lack of resources. We also recognize that many students, including students of color, students from low socioeconomic backgrounds, and students who have unmet accessibility needs may require appropriate support, in the form of thoughtfully crafted labs, to develop experimental and computational skills. Integrating these skills into required courses is vitally important, as is sharing these labs with the community of lab instructors. Consequently, a critical component of this program is the dissemination of experiments via a community repository which would facilitate revision, adaptation, and interaction.

This proposal is consistent with prior NSF DUE programs to support laboratory instruction, such as the ILI and CCLI programs, and also consistent with developing the workforce needed for the U.S. National Quantum Initiative (Fox et al., 2020 [1]) and the Grand Challenges described by the National Academies (National Academies, 2019 [2]). Moreover, it would support the development and dissemination of labs and equipment for the Living Physics initiative while expanding laboratory resources for interdisciplinary areas like biophysics, medical physics, optics and photonics, materials physics, nanotechnology, and renewable energies.

This request aligns with the *AAPT Recommendations on the Undergraduate Physics Laboratory Curriculum* (AAPT, 2014 [3]), the *AAPT Recommendations for Computational Physics in the Undergraduate Physics Curriculum* (AAPT, 2016 [4]), and the joint APS-AAPT *Phys 21 Report* (APS-AAPT JTUPP, 2016 [5]) which emphasize the importance of experimental and computational skill development in the undergraduate physics curriculum in preparing Physics majors for 21st-century STEM jobs.

We encourage the NSF to review proposals in a way that will be equitable for all types of institutions: two-year colleges, minority serving institutions, four-year colleges, universities, and research institutions.

<u>FUNDING PRIORITIES</u>

(2) PHYSICS CURRICULUM CONFERENCES

Physics educators grapple continuously with the curriculum, constrained by local institutional conditions and by an implicit, common core curriculum (SPIN-UP, 2003 [6]). The last time a broad group of physicists engaged in curricular reform was 60 years ago (Fowler, 1962 [7]), and the introductory course was considered 25 years ago (Coleman et al., 1998 [8]). In contrast, the life sciences community has undertaken a similar effort approximately a decade ago (NSF and AAAS, 2010 [9]). While physics education research has led to significant pedagogical advances, the structure of the undergraduate physics curriculum remains largely unchanged since the early 1960s. Consequently, the community of physics educators is overdue for a set of conferences on the undergraduate curriculum. The goal of these conferences is to deliver a community-guided set of curricular recommendations by leveraging the recent foundational work done by the AAPT, the APS, and the AIP, both separately and collaboratively ([3-5], AIP TEAM-UP, 2020 [10], EP3 report, 2020 [11]. The recommendations from the aforementioned professional societies have stressed the importance of skill development in preparing students for the 21st century STEM workforce. These conferences will focus on identifying needed changes in curricular and pedagogical practices and departmental culture and climate, as well as mechanisms for enabling and sustaining these changes. The main deliverable from these conferences will be a culminating report that will be disseminated to the physics community. Through synthesis of the prior foundational work and the community consensus, this report will help department chairs and administrators understand how different areas of the curriculum and co-curriculum interact and how they can be leveraged to support student learning and achievement.

Because physics baccalaureates experience low unemployment and possess skills that are useful in a variety of workplaces, one might conclude that the present curriculum is successful. However, two facts stand out: (1) Nationwide, the fraction of STEM Bachelor's degrees in physics is less than 3% (AIP, 2018 [12]), and (2) Although the percentage of Bachelor's degrees in physics earned by women has increased from less than 10% in the 1970s to approximately 20% (AIP, 2018 [12]), they remain underrepresented, and other groups, e.g., African Americans and Hispanic Americans, remain significantly underrepresented (AIP, 2018 [12]). These two facts suggest that (1) the curriculum may not be sufficiently attractive, (2) common pedagogical and evaluation practices do not retain students from underrepresented groups, and (3) academic, social, and economic support structures for students need to be enhanced. More can and must be done to recruit and retain students from underrepresented groups and increase diversity, equity, and inclusion within physics programs. The curriculum conferences will address these points. Soon, changing demographics will require increased recruitment from underrepresented groups (see Initiative 3). Community-wide consensus building is critical to project physics education into the future, to the benefit of students and a nation that is increasingly dependent on innovation and technology, especially in key areas like sustainability and security.

(3) PREPARING PHYSICS AND ASTRONOMY DIVERSITY CHANGE AGENT TEAMS FOR SUCCESS

Undergraduate physics has been plagued with equity, diversity, and inclusion (EDI) issues for decades, as identified by work produced by the American Association of Physics Teachers (AAPT), the American Institute of Physics (AIP), and the American Physical Society (APS) (APS-AAPT JTUPP, 2016, [5], AIP TEAM UP, 2020 [10], EP3, 2020 [11]). This is reflected in the representation of different groups in terms of percentages: there are racially underrepresented physicists as well as women of all races (AIP, 2018 [12]). Research suggests that there are multiple reasons for this, including some departments with unsupportive physics learning environments. Although there are faculty who are motivated to systemically address these issues within their departments, they may be hampered by a lack of EDI training, a lack of support within the department for engaging in this work, the lack of appropriate curriculum and teaching practices, and lack of time to properly and effectively take on this work. Deploying dedicated EDI change agents whose primary function is to address these issues systemically and who are appropriately trained in EDI will ensure that research-based interventions to improve physics and astronomy EDI are effective.

Because each department has a different context, with a reality that should be recognized, we envision an EDI priority that incorporates a change agent team model to support sustained change regarding EDI within physics and astronomy departments. Sustained change is generated by teams because of distribution of labor, greater buy-in by the organization, diversification of perspectives leading to stronger, and more sustainable interventions, and for many other reasons (Henderson et al., 2011 [13]). Hence, we advocate for funding departmental (or institutional) teams that will work on aspects of EDI that require considerable time and effort and will lead to substantive positive change. Some potential projects for the teams to embark on include but are not limited to: sabbatical or residency for a lead change agent on a team to learn from departments or programs that have an outstanding record in an area of EDI; a thorough assessment and evaluation of the departmental EDI goals (e.g., the Physics and Astronomy SEA Change self-assessment) followed by addressing areas of improvement; and creating partnerships between PWIs and HBCUs, PBIs, Tribal College and Universities, HSIs, AANAPISIs, and two-year colleges (TYCs). Additionally, research is still needed to understand the mechanisms by which meaningful systemic change in EDI initiatives can occur in STEM departments using a team model and we advocate for the pursuit of this research aspect outlined below.

Conceptualization of and use of funding for these projects would ultimately be up to the PIs, who would be a wide-range of entities including individual departments; coordinated networks of departments, especially those in a given region; and professional societies. The diversity in PI teams and scope of the projects will support a variety of departmental contexts; we anticipate it may be beneficial for some departments to work in coordination with other departments in order to share resources and maximize efforts. The funding for the change agent teams could in part be used for funding projects such as the potential projects noted above; hiring consultants with expertise and knowledge in EDI to help guide efforts and develop evidence-based action plans; course buyout time for faculty lead change agents to spend dedicated time on EDI efforts in both local and cross-institutional contexts; stipends for those engaging in for programmatic efforts; research and evaluation of the EDI departmental team model and on programs that are implemented; and other compensation to ensure participants can learn and do meaningful work. If professional societies apply for funding in this strand, a PhysTEC model where the professional society provides financial and administrative support, professional guidance, and other incentives to departments could be implemented.

While some of this work entails adopting research-based programs and practices, there is much to be learned. These EDI efforts are frequently developed in one particular context and do not account for modifications made by adopters. Understanding not only what modifications are made and why, but also the impact of those modifications is important to ensure the success of others adopting programs and practices and to support the future development of EDI programs and practices. Furthermore, cross-institutional partnerships around EDI practices should be studied to ensure collaborative, fruitful models. Studying the role of professional societies in advancing EDI work would help determine how the national-level work influences regional and local EDI work. At the departmental level, research is needed to understand many facets of this work including: the effects of change agents in local contexts and the effect the change agent model has on disciplinary fields with respect to equity, diversity, and inclusion; how cross-institutional learning propagates positive cultural change at participating institutions; what secondary implementation of EDI practices and programs looks like in various contexts; what sabbatical or residency models work well for different change agents, contexts, and areas of EDI; and what other support teams of change agents may need.

We anticipate that this strand will help improve departmental climate and culture, as well as provide research-based models to address these issues. By investing in EDI, the NSF can not only symbolically but also materially advance EDI efforts and knowledge to ensure an inclusive undergraduate physics enterprise and ultimately STEM enterprise for all.

(4) CREATION OF A NATIONAL INSTITUTE FOR TWO-YEAR COLLEGE PHYSICS

This initiative is in recognition of the unique role and situation of Two-Year College (TYC) physics faculty and programs. TYC faculty face five critical issues: isolation, obstacles in networking, the need to maintain pedagogical currency, and insufficient data on their students and programs (Watkins, 1990 [14]). These issues were first identified in 1996 and are ongoing within the TYC community. In addition, given the open admission of TYCs, serving a characteristically diverse population of students, it is imperative that redevelopment of undergraduate physics programs includes these key institutions.

A national survey of two-year college physics (Neuschatz et al., 1998 [15]) revealed that 60% of TYCs had one or fewer full-time physics faculty members. Another survey of TYC physics faculty across the nation found that only 51% of the faculty (White and Chu, 2013a [16]) teaching physics were full-time; this reliance on part-time faculty is in contrast to four-year institutions. To overcome isolation and provide professional development, there have been a series of NSF funded projects attempting to address these issues, including TYC workshop projects (Hieggelke, et. al, 2000 [19], O'Kuma et al., 2006 [20]), New Faculty Experience (Schultz, et al., 2015 [21]), TYC21 (Lucey et al., 1995 [22] and Palmer et al., 2000 [23]), SPIN-UP/TYC (Monroe et al., 2005 [24] and Norton, 2005 [25]), and ICP/21 (Dickinson et al., 2005 [26]). Currently these networking and professional development opportunities do not exist for the TYC community. The previous models used in the NSF grants did not allow for sustainability, and thus the need for a new National Center for TYC Physics to take up these initiatives.

Networking can help facilitate pedagogical currency. However, it is worth noting that the last AAPT guidelines for TYC physics programs were published over twenty years ago [17]. Meanwhile, the number of students enrolled in physics at TYCs almost doubled between 1995 and 2011 (White and Chu, 2013b [18]), lending support to the urgency of this initiative.

Surveys focusing on TYCs nationally tend to be lower priority (than high school, four-year, and graduate programs) for agencies and researchers, so require external funding, and are thus sporadically conducted. It is necessary to obtain more data in order to efficiently drive efforts to improve TYC physics.

From an equity standpoint, TYCs are uniquely positioned to provide a gateway for a more diverse population to enter the field of physics. TYCs provide a solid math and physics background that prepares students for a successful transition to four-year colleges and universities. Students' first experience with physics can shape their perspective and influence their decision to pursue physics as an academic major. Students with socio-economic disadvantages, learning disabilities, and students of color often lack the opportunity to enroll in institutes of higher learning were it not for the existence of community colleges. According to Bush, "Community colleges have and continue to serve as the primary pathway into postsecondary education for men of color" (Bush and Bush, 2010 [27]). Wood et al. quantify this further: "In fact, 71% of black and latino men begin their experiences in public post-secondary education at community college" (Wood et al., 2015 [28]). TYCs enroll 30% of all undergraduate students, and serve as a significant pipeline for students of color into physics, where for example, 20% of Hispanic physics graduates started at TYC (AIP report [29]).

Concerning Physics Education Research (PER), Kanim and Cid's investigation of the demographics of PER (Kanim and Cid, 2020 [30]) revealed that nearly no research is performed on physics students at TYCs. They examined the American Journal of Physics, Physical Review:

Physics Education Research, and The Physics Teacher from 1970 through 2015. Of the 417 papers they reviewed, only 6 reported on TYCs. Worse, their student sample size was 701, a mere 0.3% of the students studied in the PER papers covered. Given the difference in demographics between many TYCs and four-year institutions, this also means that students who are studied by PER are skewed by race and socioeconomic status. Moreover, the majority of PER studies use students from R1 institutions, and such results may not be applicable to the wider student body. It is imperative that PER expand to include all students, and providing funding for research explicitly on TYCs helps with such inclusivity efforts.

We envision three main prongs for this National Institute: (1) professional development for TYC faculty, (2) community-building structures, and (3) resources for curriculum and program development at institutions, and for the TYC physics community.

TYC faculty are in unique situations, providing not only content for students at the introductory college level, but often also needing to coach students in skills for successful academic pursuits. Professional development will be achieved with workshops that allow participants to train on and develop new resources, experience transformational pedagogical approaches, and engage in fruitful dialogue with peers. There is a need for archiving and sharing materials related to physics at TYCs; currently, the situation is haphazard, with much knowledge and experience held in the memories and personal bookshelves of a relatively few individuals. Continuity within the TYC physics community is necessary to ensure excellence is maintained in TYC physics programs.

References

1. Fox, M.F.J., Zwickl, B.M., and Lewandowski, H.J., “Preparing for the quantum revolution: What is the role of higher education?”, Phys. Rev. Phys. Ed. Res. 16, 020131 (2020).

2. National Academies of Sciences, Engineering, and Medicine. 2019. *Environmental Engineering for the 21st Century: Addressing Grand Challenges*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25121

3. AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum (AAPT Committee on Laboratories report, 2014).

4. AAPT Recommendations for Computational Physics in the Undergraduate Physics Curriculum (AAPT UCTF report, 2016).

5. Phys 21: Preparing Physics Students for 21st-Century Careers (APS-AAPT JTUPP report, 2016).

6. Strategic Programs for Innovations in Undergraduate Physics: Project Report (SPIN-UP report, 2003).

7. Fowler, J.M., “Progress Report of the Commission on College Physics”, Am. J. Phys. 30 (10), 665-686 (1962).

8. Coleman, L.A., Holcomb, D.F., and Rigden, J.S., “The Introductory University Physics Project 1987-1995: What has it accomplished?”, Am. J. Phys. 66 (2), 124-137 (1998).

9. NSF and AAAS, “Vision and Change in Undergraduate Biology Education: A Call to Action” (2010), https://visionandchange.org/finalreport/

10. THE TIME IS NOW: Systemic Changes to Increase African Americans with Bachelor’s Degrees in Physics and Astronomy (AIP TEAM-UP report, 2020)

11. Effective Practices for Physics Programs (APS, 2016-2020), at: https://ep3guide.org/

12. AIP Statistical Research Center, “Physics Bachelor’s Degrees: 2018” https://www.aip.org/statistics/reports/physics-bachelors-degrees-2018

13. Henderson, C., Beach, A., and Finkelstein, N. (2011). Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. *Journal of research in science teaching*, 48 (8), 952-984.

14. Watkins, S.A. (Editor). (1991). *Critical issues in two-year college physics and astronomy – 1990 and beyond.* American Association of Physics Teachers and American Physical Society, Topical Conference Series.

15. Neuschatz, M., Blake, G., Freiesner, J. and McFarling, M. 1998. *Physics in two-year colleges*. American Institute of Physics Publication R-425. Retrieved from https://eric.ed.gov/?id=ED444642

16. White, S., and Chu, R. (2013a). Number of physics faculty at two-year colleges. American Institute of Physics. Retrieved from https://www.aip.org/sites/default/files/statistics/undergrad/tyc-fac-p-12.pdf

17. American Association of Physics Teachers. (2002). *AAPT guidelines for two-year college physics programs.* Hogan, William P. (Editor-in-Charge). Retrieved from https://aapt.org/Resources/upload/TYCGuidelines-PDF.pdf

18. White, S., and Chu, R. (2013b). *Physics enrollments at two-year colleges*. American Institute of Physics. Retrieved from https://www.aip.org/sites/default/files/statistics/undergrad/tyc-enrollments-p-11.pdf

19. Hieggelke, C., and O'Kuma, T. (2000). The impact of physics education research on the teaching of scientists and engineers at two year colleges. *AIP Conference Proceedings, 399(1).*

20. O'Kuma, T. L., and Desbien, D. (2006). *ATE project for physics faculty.* NSF-DUE-0603272 and NSF-DUE-1003633. Retrieved from http://www.physicsworkshops.org

21. Schultz, S., and Leif, T. (2015). *Two-year college new faculty training experience.* NSF-DUE-1225603. Retrieved from https://www.aapt.org/Conferences/newfaculty/tyc2015.cfm

22. Lucey, C., Monroe, M. B., and Nelson, M. (1995). *The two-year college in the twenty-first century: Breaking down barriers.* NSF-DUE-9450160.

23. Palmer, James, C. (Editor). (2000). *A model for reform: Two-year colleges in the twenty-first century: Breaking down barriers*. American Association of Physics Teachers. Retrieved from http://www.physicsworkshops.org/A%20Model%20of%20Reform.pdf

24. Monroe, M.B., O'Kuma, T.L., and Hein, W. (2005), *Strategic Programs for Innovations in Undergraduate Physics at Two-Year Colleges: Best Practices of Physics Programs*. American Association of Physics Teachers.

25. Norton, M. J. (Ed.). (2005). *AAPT SPIN-UP-TYC booklet*. American Association of Physics Teachers. Retrieved from http://www.aapt.org/programs/upload/spin-up-tyc-booklet.pdf

26. Dickinson, A., Nelson, M., Cunningham, P., and Savrda, S. (2005). *Introductory College Physics / Twenty-First Century (ICP/21).* NSF-DUE-0101433. Retrieved from: https://www.nsf.gov/awardsearch/showAward?AWD_ID=0101433.

27. Bush, E.C., and Bush, L. (2010). *Calling out the elephant: An examination of African American male achievement in community colleges*. Journal of African American Males in Education, 1, 40-62

28. Wood, J.Luke, Harris, Frank III, and White, Khalid (2015). *Teaching Men of Color in the Community College: A guidebook.*

29. Kanim, S., and Cid, X. C., (2020), Demographics of physics education research, Phys. Rev. Phys. Educ. Res. 16, 020106