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The role of the HBCU pipeline in diversifying the STEM workforce: Training the next generation of drug delivery researchers

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ABSTRACT

Training the next generation of diverse drug delivery researchers is critical as there is a myriad of challenges that must be solved in the field. HBCUs have been and will continue to remain key factors in training significant numbers of diverse STEM graduates that enter a talented pool of potential drug delivery researchers. Several factors, both structural and psychosocial, play a role in preparing future African American researchers. In this review, strengths and weaknesses of the HBCU STEM pipeline are examined as well as current partnerships that better position HBCUs to recruit, train, and retain diverse researchers in drug delivery.

Contents

1. Introduction

As researchers continue to address health disparities among the population, drug delivery research and personalized medicine remain as key areas of study to reduce such disparities [1]. Such health disparities have been recently illustrated during the COVID-19 pandemic, in which the African American, Latinx, and Asian populations had significantly greater rates of infection, hospitalizations, and death than the White population[2,3]. Along with the disparities in symptom severity and death rates, there has also been widespread discussion of African Americans' history of distrust of medical professionals and the subsequent reluctance of

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African Americans to accept the COVID-19 vaccine [4]. The continued evolution of drug delivery research will be critical as the biomedical community continues to adapt to a diverse set of healthcare challenges. The recruitment of diverse talent, and the subsequent retention and training of the drug delivery workforce will continue to be essential for these required adaptations.

Science, technology, engineering, and mathematics (STEM) education research has demonstrated that there is a need for continued research and program implementation that addresses the lack of African American students who are able to navigate the STEM pipeline to a successful career. There has been great effort to increase enrollment for African American students in the STEM disciplines, and although there has been a slight increase in enrollment for these students, these efforts have not made a significant impact. The globalization efforts in engineering have steadily increased, and yet the lack of underrepresented students in engineering disciplines not only continues to present a concern for educators, it reveals the continuing need for a more diverse STEM workforce in the United States [5,6,8]. Particularly, drug delivery research has made a profound impact on society, and an increased demand in this research area is expected as progress continues in addressing current drug delivery challenges [9]. Many factors contribute to the failure to increase the participation of African Americans in STEM disciplines in general and drug delivery. A lack of primary and secondary education preparation [10], financial support [7,11], institutional racism [12,13], psychosocial factors, such as identity and academic efficacy, and a lack of African American faculty and mentors create barriers for these students [14,15,16]. Social identity development has been found to have a profound impact on outcomes across domains. Specifically, when considering the STEM pipeline for African American students, understanding whether and the mechanism by which these students develop a science identity provides insight into what experiences keep students in the pipeline. The negative racial stereotypes concerning African Americans and intelligence have been found to put racial, specifically, Black identity development in opposition to science identity development [12,13,17]

The obstacles that African American students face in STEM are lessened at a Historically Black College/University (HBCU). HBCUs are diverse institutions that provide students of all racial and socioeconomic backgrounds with a competitive education and opportunities for successful careers [18]. HBCUs continue to be relevant and even imperative for African American students because they are comprised of more faculty of color than their Predominantly White Institution (PWI) counterparts, especially in STEM disciplines in which there is an overall dearth of faculty of color [12,19,20]. HBCUs are able to provide faculty, mentoring and training that address the particular challenges that African American students face, and have succeeded in graduating a significant number of African Americans across all fields of education [20–22]. HBCUs have continuously proven their ability to recruit and retain African American students, which demonstrates the necessity of partnerships with these institutions to support and strengthen the diversity of the STEM workforce. These partnerships not only benefit African American students by introducing them to lucrative and satisfying careers, but also to the STEM disciplines by adding a diversity of knowledge, experience and background to the practice of these disciplines [7,23]. The purpose of this paper is to discuss the role of HBCUs in diversifying the STEM workforce, current programs and partnerships with HBCUs and what those mean for the future of African Americans in STEM disciplines.

2. Example of an HBCU drug delivery core

One example of an HBCU that has placed an emphasis on area of drug delivery research is Xavier University (New Orleans, LA). Xavier's NIH-funded Research Center in Minority Institutions (RCMI) programs conducts research in both cancer and health disparities. Within their RCMI program, Xavier has established a drug discovery and delivery core. This core offers services in molecular modeling, synthesis, *in vitro*/*in vivo* evaluation, and pre - formulation/formulation. The Xavier RCMI program provides pilot project funding to support faculty seeking preliminary data for external funding core areas such a drug discovery and delivery [24]. Programs such as the Xavier RCMI are critical to the training of undergraduate, graduate, and postdoc trainees as faculty can mentor them in labs and incorporate drug delivery concepts in the classroom. HBCUs such as Xavier are an ideal setting for such initiatives as they have been successful in introducing a diverse population of students to STEM, the base of drug delivery research.

2.1. Role of HBCUs in diversifying the STEM workforce

HBCUs were founded to educate African American students when they were not allowed to attend Predominantly White Institutions (PWIs) in the mid to late nineteenth century Now that African American students are able to attend PWIs more freely, there has been debate on the relevance of or need for HBCUs. Although the enrollment of African Americans across the nation's 101 HBCUs was down approximately nine percent in 2017, 23 percent of all bachelor's degrees awarded to African American students were from HBCUs (National Center for Education Statistics, 2018). Several studies have reported that HBCUs are more likely to graduate African American students with undergraduate, graduate and professional degrees than PWIs and that African American students at HBCUs are more likely to graduate than African American students at PWIs. Students attending HBCUs also tend to have higher educational aspirations than African American students attending PWIs [20–22]. HBCUs account for three percent of higher education institutions in the U.S., while one-third of African American STEM Ph.D. recipients received their undergraduate degrees from HBCUs [25].Provided that HBCUs graduate a disproportionate number of African American students, especially those with STEM programs, HBCUs are crucial stakeholders in guiding African American students through the STEM pipeline.

While a review of the statistics makes HBCUs' retention record clear, the common mission of HBCUs speak to how these institutions are more likely to retain and graduate African American students as well. HBCUs seek to create leaders across disciplines that increase social justice and cultural consciousness [26]. HBCUs allow for African American students to access Black professionals as professors, role models and mentors. These experiences allow HBCUs to go beyond education as an information and training transaction to providing an increase in efficacy and well-being [27]. HBCUs provide opportunities for students to thrive in ways that are lacking at PWIs.

2.1.1. Science identity development

HBCUs are uniquely positioned to address the impact of the challenges African American students face before enrollment and during their tenure at the institution. HBCUs are also able to provide students with the tools they need to overcome the challenges they will face in their careers [28]. One challenge the literature suggests these students are likely to have upon entering their STEM programs is a lack of a STEM-oriented self-construal, in other

words, a science identity [18,29–31]. This self-construal or identity refers to whether or not students believe that science is central to their "self" and whether or not students see themselves as and are recognized by others as scientists [13,18,30,32,33]. African American students are less likely to have or develop a science identity compared to White students because compared to their peers, as previously stated, African American students are less likely to encounter STEM faculty of color at universities, African Americans are less likely to be employed in STEM fields, and images of scientists are not likely to be represented as African American[12,18,34]. Additionally, African Americans tend to be underprepared in STEM areas before entering college and therefore do not choose to major in these areas when they enter college. African American students are also more likely to experience racism and ostracism in high school and collegiate STEM programs, which can damage science identity development [35]. A science self-construal is likely to facilitate a student's progress towards graduation and studies have further found that having a science identity was related to choosing a STEM career up to four years after graduation [36].

Identity Theory posits that identity is the result of social interaction that provides an individual with self-knowledge [32], and as such, it can be argued that while attending HBCUs, African American students are likely to develop a science identity when they employ interdependent practices, such as relevant peer-to-peer interactions, as well as well-developed relationship with faculty and mentors [37]. In invoking interdependent attitudes in that academic context, African American students begin the process of developing a science identity because the group with which they are interdependent are STEM peers and faculty. One model of science identity posits that there is a relationship between science identity and other identity domains, especially apropos here, racial identity [18]. This model also proposes that a science identity is developed when, beyond feeling competent in science, an individual is able to perform as a scientist, sees themselves as a scientist and is recognized by other scientists as a scientist (Fig. 1). It is especially difficult for African Americans to develop a science identity if they lack the opportunity (or confidence) to perform as a scientist and are not exposed to the recognition of others due to systemic racism and negative racial stereotypes regarding African Americans and science ability.

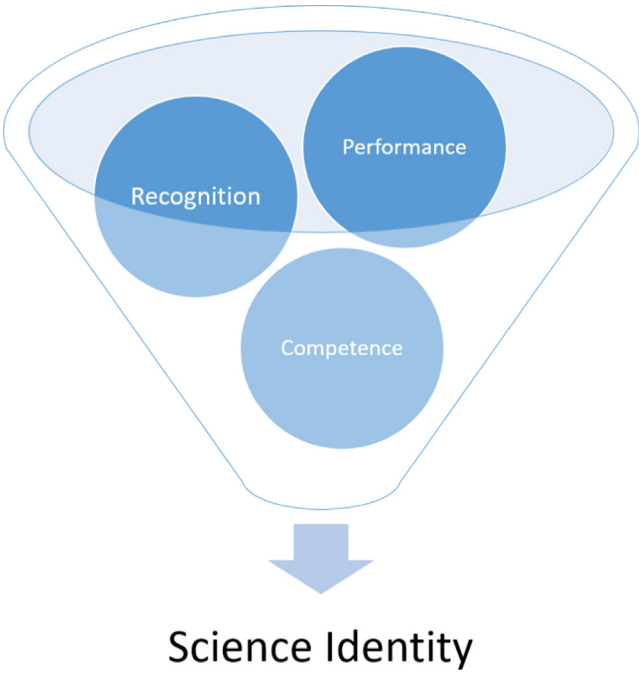

Fig. 1. Key components of science identity development as adapted from Carlone and Johnson [18].

The relationship between mentorship and science identity development may explain how African American students succeed at HBCUs and how these institutions are able to graduate a disproportionate number of African American students, especially in STEM disciplines. Science identity development is strengthened when African American students have peers, professors and mentors to help them believe they are competent in science, they are given opportunities by faculty and mentors to successfully perform science, and are recognized by these groups as scientists.

2.1.2. Mentorship

Previous research has shown the benefits of mentoring. Mentoring allows students the social capital to access knowledge about the discipline of interest and it can assist students in navigating challenges they are likely to face. Mentoring also provides students with successful role models and networks that are able to provide career opportunities. Mentors can give students psychological and emotional support, as well as assist in science identity development [38]. The Tripartite Integration Model of Social Influence (TIMSI) theorizes that students are likely to persist in their college majors when they are high in efficacy, identity and values related to that major [39]. These psychosocial variables are likely increased when students interact with an effective mentor. A study done to test the TIMSI included 1420 underrepresented undergraduate junior and/or senior biomedical/science majors (47.0% African American, 40.3% Latinx, and 12.7% other non-White racial groups) from 50 universities [36]. Students who participated in biomedical/science training programs that targeted underrepresented groups were compared to students who did not participate in any specific training program. Students' science efficacy, science identity, science values, and relationship with mentors were measured. The researchers found that effective mentoring was positively correlated with science efficacy, identity and values which helped to integrate underrepresented students into the scientific community and increased their persistence in STEM disciplines.

Mentoring that targets underrepresented groups is effective in integrating these students into STEM majors; however, it can be argued that African American mentors have an advantage when mentoring African Americans students due to their personal understanding of the students' experiences. Strategies used by African American mentors with African American protégés attending PWIs have been addressed in a previous study[40]. The mentor-protégé relationship was not entirely unique, just as in any successful mentoring relationship, the mentors provided their students with academic and career plans and provided them with resources to facilitate these plans. What may have been specifically important to African American students was that these mentors used a familial approach with their students; mentors were more likely to give advice in the same way they would to a family member. Mentors also used their own experiences to guide students. The shared experiences between mentor and protégé were especially helpful to African American students who were faced with challenges that were not shared by their White peers. This work did not focus on mentors and students in STEM disciplines, but it is intuitive that these relationships would be especially effective in disciplines in which African Americans are underrepresented [40].

Research addressing mentoring programs designed at HBCUs has also demonstrated the effectiveness of the mentoring of African American STEM students [41–43]. The Benjamin Banneker Scholars Program, at Central State University, an HBCU, was designed to increase STEM retention [41]. Freshmen to junior STEM majors with a GPA of 3.0 or higher were matched with a

STEM faculty member. Faculty members mentored between three to four students in their area. This program included structured mentoring, academic and career development workshops, and several peer activities, including shared living spaces. Students showed an increase in academic performance, they were retained in their STEM programs, and students and faculty reported high satisfaction with their mentoring interactions.

Peer-to-peer mentoring in STEM disciplines has also been shown to be effective. Peer-to-peer mentoring is considered a best practice for increasing student academic success. This type of mentoring, like the mentor-protégé relationship between African American faculty and African American students mentioned above, also allows for a shared perspective between the students [44]. The shared perspective is compounded when peer-to-peer mentoring takes place at HBCUs in disciplines that tend to lack adequate African American representation. Peer-to-peer mentoring can be an advantage for African American students attending an HBCU in majors that tend to be very competitive and hostile for African American students at PWIs In addition to those advantages, African American students in STEM may also see peer-to-peer mentoring as a responsibility they are excited to take on because they are aware that African American STEM students historically have few opportunities as well as few role models in their disciplines [45]. A study addressing the impact of peer mentoring on the mentor found that a blended mentoring program between two HBCUs targeting African American and Latinx women increased positive outcomes for the peer mentors [46]. Six female graduate students participated in the study, five identified as African American and one as Latinx. Through qualitative and quantitative data collection, the findings demonstrated that mentors experienced an increase in their STEM self-efficacy, persistence in their STEM majors, as well as interest in STEM careers. The participants also reported an increase in their mentorship and leadership abilities.

The literature makes clear the strength of mentoring, especially regarding African American students in STEM disciplines. The impact of mentoring is intuitive in that mentors provide African American students with in-depth knowledge on how to be an effective and successful student, how to overcome challenges, and the social capital needed for various career-related opportunities [38]. Mentoring is vital for African American students in STEM disciplines due to the inherent difficulties of these programs and the persistent exclusion of African Americans. HBCUs are inherently able to provide African American students with the mentoring they need as a function of faculty's role, the inclusive nature of the HBCU environment, as well as the aim of many HBCUs to provide programs that increase the number of African Americans in STEM.

2.1.3. Challenges

Despite the many successes of HBCUs in retaining and graduating African American students in STEM, they continue to be faced with many challenges. HBCUs are less likely to have the financial support matching that of their PWI counterparts. These economic challenges come in the form of endowments, federal funding, grant funding, and scholarship opportunities for students [7,42,47,48]. These challenges mean that retention is impacted by students' ability to afford their education [13]. Without the various means to assist students in their financial needs, HBCUs are more likely to lose students than other institutions. Financial hardship is also likely to influence the infrastructure and facilities needed to properly train students and conduct research, especially in STEM disciplines. Lack of infrastructure creates a cycle in which HBCU faculty are less equipped to receive the grant funding needed to help build infrastructure and further research, student training, and program expansion [23,47].

Financial challenges are further likely to increase the teaching loads for faculty who also tend to be without the assistance of graduate teaching or research assistants [49]. Increased teaching loads mean less time to development research laboratories and programs and participate in faculty development opportunities. Together these challenges make it difficult for HBCUs to provide the training students (and faculty) need without partnering with other institutions. HBCUs have made progress in maintaining and even growing their STEM programs, but remain at a disadvantage to many PWIs. Partnerships with various industries are advantageous for both HBCUs and those industries. The funding and opportunities for faculty and students are invaluable, but HBCUs also provide a highly competent workforce with the diversity needed to fuel innovation [23,42,48,50]

2.2. Current success and partnership mechanisms with HBCUs

HBCU's have produced a significant number of African American graduates in the STEM fields despite accounting for only 3% of colleges and universities[7]. Of all STEM bachelor degrees obtained by African Americans, 15.7% originate from HBCUs[51]. HBCUs are responsible for producing an even greater African American graduate percentages of drug delivery preparatory majors such as biology and engineering with percentages of 24.7% and 17.2%, respectively[51]. Impressively, four of the top five institutions that produced African Americans with engineering degrees in 2016 were HBCUs[52]. Of importance to the drug delivery workforce, four of the top five institutions that produced African Americans with bachelor's degrees in chemical, biochemical, and biomolecular engineering in 2016 were also HBCUs [52], and HBCUs awarded 47% or more of all bachelor's degrees in biomedical science from 2001 to 2009 [53]. Such successes in STEM at HBCUs provide a great foundation for a diverse drug delivery workforce that will need continued support to sustain and grow.

As drug delivery research is interdisciplinary, training can derive from a range of majors including engineering, math, physics, chemistry, biology, medical sciences, and pharmaceutical sciences [54]. The pharmaceutical sciences major directly exposes students to the topics of drug discovery, design, and delivery. Several pharmaceutical sciences programs are currently offered at HBCUs (see Table 1)[55]. The impact of HBCU pharmaceutical science programs have included undergraduate HBCU student training programs for developing nanomedicines to treat prostate cancers [56] to undergraduate programs targeted to increase enrollment, retention, and graduation of students in pharmaceutical sciences [57]. HBCU pharmaceutical science programs have great potential to serve as a hub for drug delivery ecosystems to strengthen the training of students.

Several funding agencies have provided HBCUs and other minority serving institutions (MSIs) with opportunities to support research initiatives. The National Science Foundation (NSF) has established several such programs including the HBCU-Undergraduate Program (HBCU-UP) and Partnership for Research and Education in Materials (PREM) programs. The HBCU-UP program, which is in the Division of Human Resource Development, is designed to strengthen STEM undergraduate research and education at HBCUs. Tracks in the HBCU-UP program include goals such as the creation of new theory-driven models to promote success of underrepresented groups in STEM, research support for HBCU STEM faculty, and support for broadening participation research[58]. One example of the impact of the HBCU-UP program on drug delivery research was the Hampton University NanoHU Program. The NanoHU Program integrated multidisciplinary STEM research and education in nanoscience, accomplishing a new Hampton University Nanoscience minor, new nanoscience courses, a scholars/fellows program, a summer research outreach program,

Table 1
HBCU Institutions with Pharmaceutical Science Programs [55].

List of HBCUs with Pharmaceutical Science Programs				
		2019–2020 Academic Year		
Pharmaceutical Science Institution	**Location**	**Enrollment**	**STEM Graduates**	**Health Professions and Related Graduates**
Elizabeth City State College	Elizabeth City, NC	1769	56	0
Florida A&M University	Tallahassee, FL	9626	222	551
Hampton University	Hampton, VA	4293	139	160
Howard University	Washington DC	9399	231	360
North Carolina Central University	Durham, NC	8011	180	191
Texas Southern University	Houston, TX	9034	227	245
University of Maryland Eastern Shore	Princess Anne, MD	2886	145	115
Xavier University	New Orleans, LA	3325	207	186

Table 2
HBCU NSF PREM Awards that Incorporate Bio-based Research Areas.

Year	HBCU	Partner	Bio-based Research Area
2012-present	Hampton University	Brandeis University	Bioinspired Soft Materials and Biophotonics
2006-present	Jackson State University	University of California Santa Barbara	Bioinspired 3D nanocomposite

and a nanoscience seminar series [59]. HBCU-UP supported programs such as NanoHU provide the critical funding and facilitates intercampus partnerships needed to advance drug delivery research on the campuses of HBCUs.

The PREM program, which is a part of the Division of Materials Research (DMR), establishes partnerships between MSIs and research centers (supported by DMR) to increase recruitment, retention and degree attainment by underrepresented groups in materials research. Table 2 illustrates PREM centers with bio-related research themes. Simultaneously, the program supports excellent research and education endeavors to strengthen institutional partnerships. Such NSF programs have enabled faculty to conduct drug delivery research through funding and the development of partnerships with DMR research centers. The PREM programs have several similar elements that are aimed to address challenges experienced by HBCUs (see Fig. 2), including access to expert collaborators/instrumentation, supplemental mentoring, and faculty/trainee exchange[60]. Expert collaborators and the access to instrumentation at DMR research centers lowers the activation energy to conduct drug delivery research at HBCUs as it addresses the lack of resources as research infrastructure continues to grow. Supplemental mentorship is vital for both HBCU faculty and student participants. Technical mentors are important as junior HBCUs seek additional grant funding and grow within their particular field of research. Student participants receive supplemental mentorship as they are encouraged to participate in summer research experiences at the partner DMR research center. This mentorship component is facilitated by faculty/trainee exchanges with each group spending significant time conducting research at the DMR center.

HBCUs, via PREM partnerships, have produced original drug delivery research in several key areas. Such PREM work studied photoswitchable materials that have the potential to be used for the controlled release of molecules [61,62]. Lipid-drug delivery conjugates have also been developed to enhance drug delivery by improving oral bioavailability, enhanced targeting, and reduced toxicity [63]. PREM HBCUs have produced work and reviews in nanotechnology to study nanoparticle cytotoxicity and functionalization of candidate and novel nanoparticles for biomedical application [64,65]. In the area of computational research, PREM HBCUs have simulated the formation of DNA-mediated hydrogels and their resulting drug loading ability [66].

The original work produced by PREM HBCUs impacts several participant groups as PREM programs train postdoctoral fellows, graduate students, and undergraduate students to obtain both permanent positions and further training in drug delivery research. The involvement of such participants in original research provides authentic research experiences and technical mentorship that improves science identity, particularly for the undergraduate participants[67]. Undergraduate participation in PREM exposes students to interdisciplinary research and an ecosystem of diverse mentors. This diverse mentor ecosystem includes near- peer mentoring of multiple backgrounds and races to increase the likelihood of self-identification. This exposure contributes to the improvement of participant academic efficacy in the critical STEM areas that prepare them for potential career in drug delivery research.

Components of the NSF funding mechanisms outlined and similar mechanisms are designed to addresses challenges at HBCUs. For example, funding for course release time is intended to reduce the course loads of HBCU faculty. Funding for postdoctoral fellows

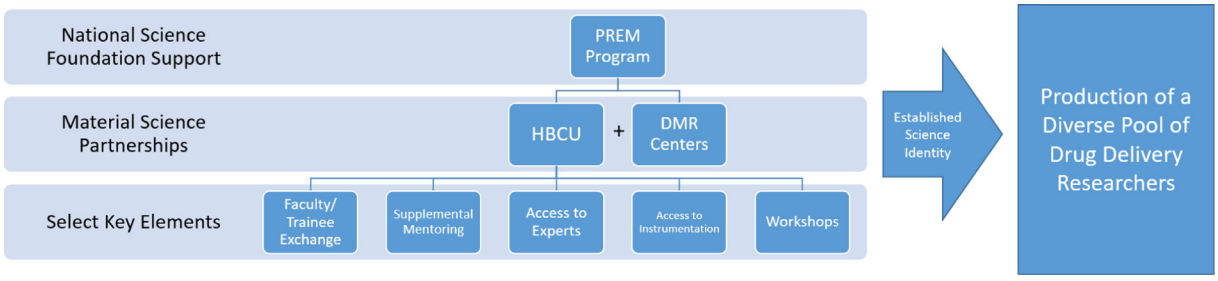

Fig. 2. The effect of external support and partnerships on the establishment of HBCU student science identity and production of diverse drug delivery researchers.

increases the number of experienced researchers on HBCU campuses to also offset the challenges of heavy course loads and provide supplemental mentorship to undergraduate and graduate trainees. Further, HBCU-targeted aware mechanisms provide funding for equipment that improves the critical research infrastructure to conduct impactful drug delivery research. In cases in which equipment is still unavailable, built-in partnerships encourage the sharing of equipment between research-intensive universities an HBCUs that aspire to conduct drug delivery research. Increasing the amount of support for these types of mechanisms and interventions would further strengthen the pathway to STEM careers for HBCU students.

Similar to NSF, the National Institute of Health (NIH) has developed multiple programs that facilitate drug delivery research at HBCUs. Two examples of such programs are the Maximizing Access to Research Careers (MARC) and Undergraduate Research Training Initiative for Student Enhancement (URISE) programs. Both programs are designed to train a diverse pool of undergraduates who pursue advanced degrees in the biomedical sciences. However, the URISE programs are intended for research-active institutions that grant bachelor degrees and receive less than $7.5 million (average) of NIH funding over three fiscal years[68], which characterizes most HBCUs. NIH URISE and MARC awards are specifically awarded from the National Institute of General Medical Sciences (NIGMS), and are HBCUs that are awarded U-RISE must establish plans for recruitment to enhance diversity, retention plan, and outcomes. Examples of long-term outcomes of the URISE and MARC programs are to provide participants with an understanding of the biomedical disciplines, scientific reasoning training, research design training, research experience, and knowledge of professional skills for transition in to the biomedical research workforce. Participants of MARC have been successful in pursuing advanced degrees as 29.2% of them earning their doctorate degrees between 2001 and 2005[69]. Such success further strengthens the pipeline of talented students that are trained at HBCUs.

3. Outlook for the future

When examining the significance of the establishment of HBCUs and the role they play in training students to become STEM leaders within their communities, these institutions will continue to prepare pupils for the professional needs of the nation in drug delivery research. This preparation is evident by the current success of African American STEM graduates from HBCUs. There is continued opportunities for growth as successful models of HBCU student training and partnership programs are disseminated throughout the country. The support mechanisms presented in this paper have been shown to help minimize the challenges that researchers at HBCUs experience. However, there still remains great potential for drug delivery research to grow among all HBCUs as all are not fortunate to have extensive funding from agencies such as NIH or NSF. Four key pillars of support (Fig. 3) are vital for HBCUs to focus more STEM trainees on drug delivery research, including faculty exchanges among research intensive universities, increased funding mechanisms, increased industry partnerships, and drug delivery focused research meetings that provide a platform for dialogue. Such initiatives would improve dialogue and partnerships between HBCUs, government agencies, and industry and will continue to facilitate the success of HBCU graduates in STEM.

As drug delivery research partnerships continue to strengthen and increase, the pool of diverse, talented drug delivery researchers will expand. The establishment and maintenance of a strong research ecosystem that promotes activity in key drug delivery research areas will remain a critical factor in training. Continued communication between HBCU STEM faculty and the broader community of drug delivery researchers in both academia and industry will remain a critical driver to maintaining the ecosystem as this engagement will continue to expose trainees (i.e., postdocs, grads, undergraduates) to key research and continue to drive HBCU research directives. Further, the infrastructure at HBCUs has great

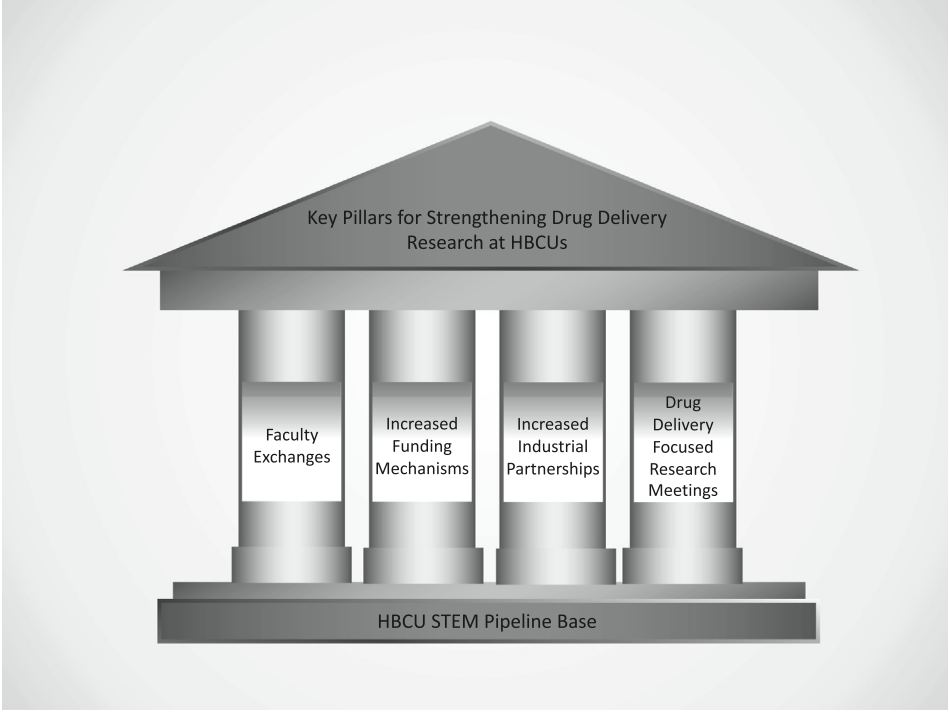

Fig. 3. Four key pillars to strengthening drug delivery research at Historically Black Colleges and Universities.

potential to grow as they continue to increase engagement in the expanding field of drug delivery research. This growth includes new facilities, the hiring of new research faculty/staff, and the establishment of additional interdisciplinary programs (e.g., pharmaceutical sciences). With continued support, the HBCU STEM pipeline will remain strong and subsequently enhance the diversity of researchers in the area of drug delivery as innovative solutions are developed for the world's complex challenges.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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