From STEM to Society: Lessons Learned from ARIS Broader Impact Project

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Abstract

I participated in the "baseline study," examining 32 faculty research grant proposals from a variety of STEM (science, technology, engineering, mathematics) fields submitted by faculty across multiple departments on a single university's campus. We analyzed the broader impact statement in each of the 32 proposals using the Center for Advancing Research Impacts in Society (ARIS) broader impact (BI) Toolkit. This essay is a comprehensive review I attempted of BI strategies recommended by NSF and the ARIS Toolkit. My voice in this essay carries forward some of the impressions I perceived from interacting with NSF applicants' proposals submitted by the faculty at the study site. Moreover, the essay is set in the backdrop of my academic and professional background in medicine, public health, human resource administration, and heath communication and social influence. Views on cross-cultural comparisons are included with reference to broader impacts between United States and Pakistan as a developing nation.

I got involved with the Center for Advancing Research Impacts in Society (ARIS) project while working as a graduate research assistant at the Center for Faculty Excellence at the University of Oklahoma (OU). As a current doctoral student of health communication and social influence with a decade-long experience in public health, health services research, and human resources administration, I quickly gained an appreciation of the National Science Foundation's (NSF) efforts to promote the broader impact of science in society by starting at the core of all the NSF sponsored research.

I participated in the "baseline study," examining 32 faculty research grant proposals from a variety of science, technology, engineering, and mathematics (STEM) fields submitted by faculty members across multiple departments on one university's campus. We analyzed the broader impact (BI) statement in each of the 32 proposals using the ARIS BI Toolkit (ARIS, 2023). The purpose was to assess how accurately the authors understand the standards expected of them by the funding agencies, especially NSF, to conduct socially beneficial research. We also wanted to examine applicants' comprehension of the skillset they need to master for strategically and constructively connecting the research studies within the broader impacts. Moreover, it's also instrumental to determine scientists' original stance on their paradigmatic approach to research ontology and epistemology.

Navigating the ARIS Toolkit: A Beginner's Guide

Previously, before starting the ARIS broader impact project, I have been involved in healthcare services research aimed at benefiting the consumers of healthcare services. However, it was only after getting involved with the broader impact project, using the ARIS BI Rubric and interacting with faculty proposals, that I started thinking about how STEM research—however technical and seemingly carrying a very narrow focus within a given discipline—can greatly benefit society.

Broader impact initiatives, at the principal forefront of their objectives when studied through the lens of the ARIS Toolkit and to an extent through faculty research proposals analyzed, aim to educate people of all age groups within and outside the formal education system without any prejudice. Broader impact serves to impart knowledge equally and equitably to both the young and the elderly, with the intention of developing creative and progressive mindsets without anticipating any direct benefits. Broader impact initiatives strive to privilege inclusion over exclusion through equitable access to and representation of all minoritized groups—racial

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and ethnic minorities, women, indigenous groups, disparate communities as well as other minorities (ARIS, 2023).

The realization and awareness of the designs and purpose of broader impact therefore have tremendously influenced the way I currently think about research and education. However, a caveat to consider is that interpreting broader impact solely in terms of *means to educate the public*, without explicitly recognizing the underlying emphasis on inviting public engagement and participation, could translate to adding to echoes of *deficit mindsets* (Bauer et al., 2007; Dawson, 2019). Therefore, implementing the ARIS Toolkit by understanding its true objectives and goals is crucial for enabling public participation through engagement.

Navigating the ARIS Toolkit: Integrating Insights from Literature and Applied Science Communication

As a life-long STEM enthusiast, observing from the outside, it seems reasonable to assume that adequate exposure to ingenious research and inventions will foster knowledgeable minds—minds that are self-motivated and self-empowered to contribute to individual welfare nationally as well as at the global pulpit. However, as a researcher with a post-positivist approach and a progressively deepening appreciation of both quantitative and qualitative research methodologies, I understand the nuances of the last four decades of survey research on public understanding of science (Bauer et al., 2007). I agree that science communication and its processes require sustained, strategic, and periodic evaluations. Qualitative research or interpretivism and being aware of multiculturalism also open one to critical perspectives in research. One can advance research impact in society when research protocols and their real- world application design processes take into account societal biases propagated through prevailing societal injustices (Dawson, 2019). Prevailing norms and systems—for example how the contents of science education in museums favor elite scientific voices while neglecting the sensemaking perspectives of racial and ethnic minorities—can hinder large-scale community acceptance of science (Dawson, 2019).

Consequently, the NSF's commitment to addressing these issues through the implementation of the ARIS Toolkit has the potential to transform science communication, its dissemination within communities, and the public acceptance of science.

Cross-Cultural Perspectives

A Pakistani Woman's Pursuit of Knowledge and Impact

I am a Pakistani born woman and I received a Doctor of Medicine[1] (MD) from Jinnah Sindh Medical University in Karachi Pakistan. After completing my mandatory clinical internship and working an additional year in hospitals in Pakistan, I finished the United States Medical Licensing Exams. I then pursued a master's in public health focusing on epidemiology and biostatistics from the College of Public Health (COPH) at the University of Oklahoma Health Sciences Center (OUHSC) in the United States. Soon after graduating from COPH, I began working as a research analyst for a variety of healthcare service–oriented programs within Oklahoma; during this time, I also earned a master's in human resources administration. While helping implement and evaluate a variety of clinical-based and community-centered projects, I came to understand the importance of conducting needs assessments with demographically varied populations. In 2022, I started my doctoral program in health communication and social influence at OU. While reviewing the rigors of research methodology and learning the theory and principles of communication, I was also exposed to ARIS, the broader impact project. This project streamlined for me the standards needed to be observed for broader impact incorporation into STEM fields. It also made me wonder what STEM—and therefore broader impact—does for developing countries like Pakistan.

Brief Review: Pakistan Versus the United States

Statistical Overview. In my career and educational pursuits, I have found the purpose of research to be manyfold. It begins with the process of discovery of the unknown where new knowledge is created with an intent to disseminate the information to a larger society once the research operations unfold. The U.S. is among the top investors in the world, with China, Israel, South Korea, and Switzerland among other countries that spend the most on research and development (R&D) (National Center for Science and Engineering Statistics, 2023). However, the U.S. spends the most in dollar amount on R&D (National Center for Science and Engineering Statistics, 2023). Bruce J. MacFadden, in *Broader Impacts of Science on Society*, explains the continued efforts of the U.S. government since the enactment

[1] Equivalent to Bachelor of Medicine, Bachelor of Surgery (MBBS) in Pakistan

of NSF Act of 1950 (Public Law 81-507) to promote the nation's welfare through offering funding incentives for science and research (MacFadden, 2019). Many creative projects have been funded since for scientists throughout the U.S., and these projects have tremendously benefitted both society and industry through a wide array of innovative approaches (MacFadden, 2019).

Compared to the U.S., Pakistan is a developing country with a very low literacy rate—58% by United Nations Educational, Scientific, and Cultural Organization (UNESCO) definition—and lower literacy rates exist in STEM education (UNESCO, 2019). This is compared to a 79% literacy rate in the U.S. (National Center for Education Statistics, 2019). Pakistan spends a very low percentage of its gross domestic product (GDP) on education, up to 2%, and an even lower percentage is spent on R&D, 0.16% (Trading Economics, 2024; World Bank Group, 2021). Compared to Pakistan, the U.S. spends a total of 6.4% on education and 3.457% on R&D (National Center for Science and Engineering Statistics, 2023). Differences between the U.S. and Pakistan go far beyond this gap in education and R&D interests. Pakistan is a developing country with the current poverty level exceeding 37%; $3.65 is earned per day for families with an average size of 6.4 people per family (Michael Bauer Research, 2022).

Putting Context to Norms in Pakistan. State, regional, and individual daily priorities differ greatly between the U.S. and Pakistan given the remarkable differences in population densities, land demographics, and a relatively homogeneous population in Pakistan, as well as the differential impact of climate change and the preeminence of religion (Fatima et al., 2024; Hussain et al., 2019; Kamran et al., 2014; Soomro & Raza, 2020). With increasing economic instability in Pakistan and deteriorating livelihood earning potential for the average citizen, the immediate focus is not on gaining a deeper understanding of STEM fields. However, literature and practice document that Pakistanis participate enthusiastically in science-related activities when the government and for-profit/nonprofit organizations make efforts to involve citizens in citizen science projects and community-based participatory research (IQAir, 2024; Karmaliani et al., 2009). Unfortunately, the scope of most such initiatives/projects has not been broad enough to involve Pakistani citizens to a measurable extent (Soomro & Raza, 2020).

Communicating Science in Pakistan. The Pakistani government and its pupil are aware of the rapidly progressing, fast-paced technological, scientific, and economic pace of the world. Since the country's inception in 1947, both before and after the adoption of the first national science and technology (S&T) policy in 1984, the government has taken several successful initiatives under the visionary leadership of scientists like Professor Salimuzzaman Siddiqui and Professor Abdus Salam to promote science communication (Soomro & Raza, 2020). These figures led the country towards an era-specific industrial revolution and resulted in extensive collaboration between local and international scientists, with efforts continuing to this day to an extent (Soomro & Raza, 2020). Whenever science communication efforts faltered, the responsibility often fell on our bureaucratic leaders who lacked a scientific background (Soomro & Raza, 2020).

The Higher Education Commission in Pakistan has substantially funded many STEM institutions since 2002 to encourage quality research production through infrastructure development (Soomro & Raza, 2020). However, the lack of strategic planning and periodic evaluation by these institutes of higher learning does not guarantee optimal resource utilization (Murtaza & Hui, 2021; Soomro & Raza, 2020). Moreover, further skill training for institutions and researchers is needed to produce quality publications that are creative and innovative enough to influence R&D on the global platform (Murtaza & Hui, 2021; Meo & Jawaid, 2021). Perhaps strict quality assurance surrounding resource optimization, guided by existing and reformed educational policies, an academic audit system, and faculty professional development training, could bring merit to initiated efforts (Meo & Jawaid, 2021; Ullah et al., 2011). Although research conducted in universities is shared among scholars in conferences and seminars, it is not done frequently enough or on a large enough scale; however, there are ongoing efforts aimed to improve this situation (Meo & Jawaid, 2021). The dissemination of scientific information is also limited due to restricted media coverage, stemming from a lack of science journalism (Soomro & Raza, 2020). Despite this, mediums like online radio and YouTube have begun to be used in many universities to promote public literacy and engagement (Soomro & Raza, 2020).

Lessons learned from science communication, its research, and evidence-based outcomes in the United States and elsewhere can serve as a basis for conducting a needs assessment for science communication in Pakistan and evaluating the consequences of its absence. This could provide an emphasis for introducing science journalism courses into journalism curricula in Pakistan.

Science Communication in Diverse Contexts: A Comparative Study of the ARIS Toolkit and Similar Initiatives in Pakistan

Cultivating Curiosity Across the Lifespan

I have learned that at a very instinctual level, discoveries and knowledge gained from science must be leveraged to pique curiosity and interest of nations worldwide, inspiring a thoughtful mindset that is open to or acknowledges the transformative power of scientific rigor in societal advancement. Knowledge and the strategies for disseminating information must be catered to the needs of all age groups (adolescents versus elderly) equitably irrespective of the judgment of individuals' perceived learning and/or productivity potential. The elderly—individuals age 65 and above—after all contribute to 34% of the global GDP and form 10% of the world's total population (AARP, 2022; Ritchie & Roser, 2024).

Evaluating the NSF applicants' proposals, I thoroughly enjoyed scientists mentioning bringing their research to individuals of all age groups via museums, physical or virtual. It was also interesting to note that free lifetime learning can be encouraged for all age groups through scientific displays in shopping malls, airports, subways, train stations, public fairs, and social media showcases (MacFadden, 2019). This provides a very powerful idea for the dissemination of knowledge outside formal academic settings to stimulate thinking and provoke curiosity, interests, and logical questioning for all.

Amidst escalating ageism concerns in Pakistan which parallel global trends, Rizvi Jafree and colleagues (2022) observed higher odds for life satisfaction among the elderly associated with learning opportunities for elderly. Inviting everyday learning through the avenues mentioned herein, it is possible to substantially augment older adults' contentment in life in Pakistan and elsewhere.

Museums and Everyday Science Learning

As I mentioned previously, learning about museums through faculty research proposal evaluation as a potential medium to promote everyday science learning was refreshing. MacFadden (2019) notes that the proportion of the U.S. population that annually visits museums across the U.S. parallels that of K-12 school attendance, a statistic that designates museums as a powerful medium for communicating science. The broader impact statements of faculty-proposed ideas involve facilitating and integrating one's research and project-derived research talks into existing museum operations, introducing a synergistic opportunity for collaboration. They also suggested developing their research-based online catalog and resources for museum libraries—an innovative approach to promote equitable access to scientific knowledge.

Reading about museums' potential involvement in promoting science communication can be a fascinating revelation. However, MacFadden (2019) does not necessarily emphasize how museums currently perpetuate and entrench the culture of social injustices. The lack of equal and equitable access, evident in ticket prices, render spaces like museums unaffordable to many creating inaccessible destinations—a hallmark of systemic access issue (Dawson, 2019). The absence of multilingual information and resources hinders visitors' ability to fully engage with museum facilities, as without essential literacies, many visitors report having disconnected experiences (Dawson, 2019). Dawson (2019) also notes that generating awareness and acceptance of science among racially, economically, and culturally disparate groups requires their involvement in designing and managing these facilities, their representation among the staff, and the cultural context within which the scientific knowledge is displayed. Therefore, after initial exposure to the ARIS Toolkit, it might be up to the centers for faculty development and community engagement at individual universities to cultivate in-depth understanding of how to effectively involve science communication mediums for broader impacts within the context of individuals' STEM research.

In Pakistan, the Ministry of Science and Technology established in 1972 through the Pakistan Science Foundation (PSF) has successfully established many science centers, clubs, museums, herbaria, and planetaria in collaboration with for-profit and nonprofit bodies (Soomro & Raza, 2020). Over time, PSF has organized conferences, seminars, science fairs, and caravans, especially for rural areas, to promote science communication. However the scope is limited due to limited funding, a lack of stable and well-informed governance, and inaccessibility to resources available in Urdu and other locally spoken languages (Soomro & Raza, 2020).

Designing Research with Teachers as Partners

After getting involved with ARIS, I have given considerable thought to how NSF inspires researchers/scientists to partner with K-12 instructors and teachers in the United States. STEM scientists can be coached to partner with teachers to design a didactic and field-based approach that enhances students' learning, allowing other system-based hurdles to be overcome through mutual collaboration. Designing research with teachers as participants as well as stakeholders can further earn credibility of the scientific notion among teachers, potentially leading to innovative curriculum configurations that stimulate young minds. Through collaboration with K-12 novice scientists and doctoral students, those offering lectures at local schools learn to translate complex phenomenon in science for budding minds. Together with the students and the instructors, they learn the art of critical skills for science communication. Additionally, such mutual planning and similar avenues will foster instructors' engagement through underscoring the potential for personal and professional growth—such as procuring unique skillsets for challenging educational planning and other didactic approaches. Scientists, however, must be careful to assess the needs and requirements of their young audience and teachers first, within the background of the communities that raise them, so maximum benefits can be gained for these students.

In Pakistan, science fairs, competitions, and caravans have been instrumental in communicating science to local schools (Soomro & Raza, 2020). Programs like Alif Aillan in 2013 through 2018 successfully incentivized students and parents and the community to demand quality education, especially quality science education (Soomro & Raza, 2020). The role of schoolteachers as collaborators with scientists is fluid: a fertile ground for transformation through ARIS learned lessons.

Synergistic Teamwork: A Key to Unlocking Scientific Success

I am now very cognizant of the fact that research and broader impacts are not carried out by only one person. The NSF encourages principal investigators to employ students from diverse racial, ethnic, and cultural backgrounds at the undergraduate, graduate, and postgraduate levels to join their research team. Selection of women is particularly urged.

At many pragmatic levels, effective mentoring and training can be achieved when crucial skillsets are bestowed amidst learning novice ideas. Involving undergraduate, graduate, and post graduate students in community outreach and engagement helps train their minds to evaluate science and its impact, regardless of the field and project, within the broader scope of its global impact. Furthermore, these trainee students/researchers can be utilized as a peer resource to design undergraduate-, graduate-, and postgraduate-level courses for broader audiences. Many projects in one discipline can also avail the knowledge of multiple disciplines through an inter/multi/trans-disciplinary approach, enabling essential skillsets to be leveraged within the institute through interdepartmental pools.

Given that Pakistan is a collectivistic culture with an interdependent self-construal, working in the formation of formal/informal teams is second nature to Pakistanis. However, there is a science to the effectiveness of fully functional teams that can be simulated by observing, enacting, and exercising practice-based strategies. One can gain a deeper appreciation of such routines when one sees clinical medical teams composed of physicians, nurses, technicians, and other medical staff working together to save patients' lives in emergency departments and intensive care units. Pakistanis are deeply familiar with the spirit of such synergistic teamwork.

I am convinced that seamless access to the current philosophy and evidence of team science, together with high-quality internship opportunities based on evidence-based training, can cultivate both skill and professionalism in growing minds. The Leadership Education in Neurodevelopmental and Related Disabilities (LEND) programs, overseen by the Association of University Centers on Disabilities (AUCD) and funded by the Maternal and Child Health Bureau (MCHB), is an example of such internship opportunities (AUCD, 2024; Center for Learning and Leadership, 2024). Intentionally crafted leadership didactics, paired with substantive fieldwork and interdisciplinary classroom environment provide a rich experience in LEND. This combination prepares graduate students from diverse disciplines for successful post-graduate professional lives and fosters transdisciplinary alliances. Hence undergraduate-, graduate-, and postgraduate-level education carefully designed to include elements of collaborative team dynamics can further refine collaborative spirits—leading to the unfettered success of broader impact projects.

The Collaborative Advantage: Unlocking Broader Impact Through Partnerships

The ARIS broader impact project has only served to reinforce my belief in stakeholders' involvement and support. As much as the cooperation of an entire research team is required to conduct seamless research, the ability to secure essential resources from partners, advocates, and stakeholders from outside the institute and from industry not only ensure harmonious conduct of research but also guarantee the removal of unexpected hurdles when stronger, larger, and higher-quality partner networks are retained.

Partners and external collaborators' viewpoints add an additional facet to novice research approaches, especially in the domain of broader impact solutions. Partners can be extremely effective in the widespread dissemination of knowledge, given their expertise, resourcefulness, professional and social networks, and interests. As with any audience and partnership, maximum utility can be achieved by assessing partners' current needs and requirements.

Many health services projects I have worked on were centrally funded by the MCHB, which had funds (Title V Block Grant) appropriated to local nonprofits and OU-based programs through state agencies such as the Oklahoma Department of Human Services (OKDHS) (Health Resources and Services Administration Maternal & Child Health, 2024; Oklahoma Department of Rehabilitation Services, 2024). MCHB and OKDHS allocated enough funds to needs assessments and R&D, reflecting outcomes of children with special healthcare needs (CSHCNs) and their families.

Many employees at those agencies were themselves either parents, grandparents, or siblings of CSHCNs and had a true stake in these projects. These programs or agencies serving the CSHCNs and their families were directly affiliated with behavioral and developmental pediatrics at the OUHSC (Sooner SUCCESS, 2024; OU College of Medicine, 2024). Other stakeholders included private businesses, such as Kendra Scott Jewelry and local S&B's Burger Joint, which were often the avenues of fundraising for CSHCNs. It is worth noting that trainee pediatric residents were regularly encouraged to attend trainings at the nonprofits and community-based programs at OUHSC to familiarize themselves with the needs, values, priorities, and community-related outcomes of CSHCN populations.

Public health or community-based health programs in Pakistan are involved in collaborative efforts with stakeholders as community members and leaders of the collaborative private sectors in private universities, like Agha Khan Medical University (The Agha Khan University, 2024). However, these practices are not widespread in many other local STEM universities throughout the country, where everyday students are not able to benefit from cooperative norms and practice-based training on collaborative work (Hali et al., 2021).

SMART Evaluation: A Crucial Component of Research Excellence

The NSF states that research processes involve not only research procedures, methods of conduction, strategic outlines, and delivery, but also the ways and means of evaluating researchers' efforts throughout the course of the project. Most evaluations are conducted using the Specific, Measurable, Achievable, Relevant and Time-bound (SMART) criteria. Its purpose is to accurately and efficiently set goals for project management. While rigorous research methodology demonstrates the validity, reliability, and generalizability of research findings, the SMART criteria clarify goals and objectives, thereby supporting those research procedures (Adeoye & Adong, 2023). Using the SMART criteria not only illustrates that the research can be replicated but also enhances the transparency of the proposed procedures, guiding their timely completion and rendering effective results (Adeoye & Adong, 2023). This, in turn, assists with procuring further funding, consequently ensuring research sustainability. The same applies to affective budgeting and accountability, where effective charting and budget analysis can track how and where the research grant money was spent.

Before starting the doctoral program in health communication and social influence, I worked as a research analyst, where I was involved in SMART evaluations of many processes. A good example is the project I worked on, which focused on innovative approaches to child welfare service delivery in Oklahoma (Bard et al., 2020). Through my engagement with the ARIS project, I realized that many researchers tend to place project evaluation on the back burner or use metrics that are not robust and fair. Learning how to conduct SMART evaluations can be beneficial to researchers worldwide, including those in the U.S. and Pakistan.

Empowering Underrepresented Groups through Inclusive Research

Before coming to the communication department at OU and joining the ARIS project, I worked with programs serving many marginalized, disparate, and underserved population as well as children and adults with disabilities. I completely comprehend NSF's urgency in forming research teams that include women and students from minority groups such as Black, Hispanic, and Indigenous populations so that these students can not only self-empower and self-motivate but also lift their communities along the path they are likely to pursue after getting involved with broader impacts.

Conclusion

As a student I have diverse academic experience in medicine, public health, human resource administration, and health communication and social influence. Both as a student and as a professional, I have appreciable experience within the psychosocial domain of healthcare services research and research methodologies. I came to the ARIS project with an understanding of servicing consumers of healthcare, and, within that domain, I understood providing medical and community-based services for demographically diverse populations in Oklahoma. What I lacked when coming on board was a comprehensive understanding of what broader impacts entail in the context of STEM education and research. Interacting with NSF proposals of 32 applicants, reviewing NSF history, and familiarizing myself with literature, evidence, and issues in the public understanding of science has deeply impacted the way now I will think of research and education. It also profoundly inspired the way I will continue to brainstorm creative broader impact solutions for R&D that benefit my people back in my home country of Pakistan.

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