Visualization Viewpoints

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How Visualization Can Foster Diversity and Inclusion in Next-Generation Science

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Visualization taps into the very best capabilities of our brains, transforming fundamentally abstract numerical data into something that communicates and illuminates information ranging from the simple to the complex. Visualization researchers, developers, practitioners, and educators routinely work across traditional discipline boundaries, oftentimes in teams of people that come from a diverse blend of backgrounds, using visualizations as a common language for collaboration. As a community, we are native interdisciplinary thinkers, working at the intersection of science, art, engineering, and technology. By definition, this intersection space is a celebration of diversity, a space in which creativity is allowed to flourish and innovation is key.

There is a looming global workforce shortage in the computational science and high-tech space, primarily due to a disconnect between population demographics and the demographics of those educated to fill these jobs. The visualization community is uniquely positioned to bring a fresh approach to making diversity and inclusion fundamental tenets that are necessary rather than desirable.

Inspired by the IEEE Visualization Conference 2016 panel, "On the Death of Scientific Visualization," this article provides rationale for what we as a community can and should do to bring our native universal language to bear on problems that have the potential to make a significant societal impact and encourage and foster innovation at every step.

A Shifting Workforce

According to the 2014 US Census Bureau, there were more than 20 million children under five years old living in the United States at that time, and 50.2 percent of them were minorities. Current birth and death statistics suggest the US is projected to become a majority-minority population by 2040.

In turn, the US Bureau of Labor Statistics projects 1.4 million computer-science related jobs will be available by 2020, with only 400,000 graduate students qualified to fill them. This leaves a staggering deficit of 1 million unmet high-tech jobs in the US alone. Several factors contribute to this shortfall:

- Computer science jobs represent 78 percent of all science, technology, engineering, and mathematics (STEM) occupations. Yet, according to the US Bureau of Labor Statistics, only 8 percent of STEM graduates are in computer science.
- Overall, women's representation in computer occupations has declined since the 1990s.[1]
- In 2011, 11 percent of the workforce was African-American, while 6 percent of STEM workers were African-American. Although the Hispanic workforce has increased significantly from 3 percent in 1970 to 15 percent in 2011, Hispanics were only 7 percent of the STEM workforce in 2011.[1]
- The numbers of Native Americans, Pacific Islanders, and Indigenous Peoples have been historically low in STEM employment, registering consistently in the low-single-digit percentages.[1]

Figure 1 shows the current US workforce shortage for jobs requiring computer science skills. Although underrepresented minorities in computer science differ in demographics by country, the McKinsey Global Institute predicts a 2020 global workforce with the requisite college and postgraduate education qualified to fill just 13 percent of projected labor demands worldwide.[2] India and Brazil are rapidly increasing STEM enrollments through targeted enrollment programs. Europe, however, is

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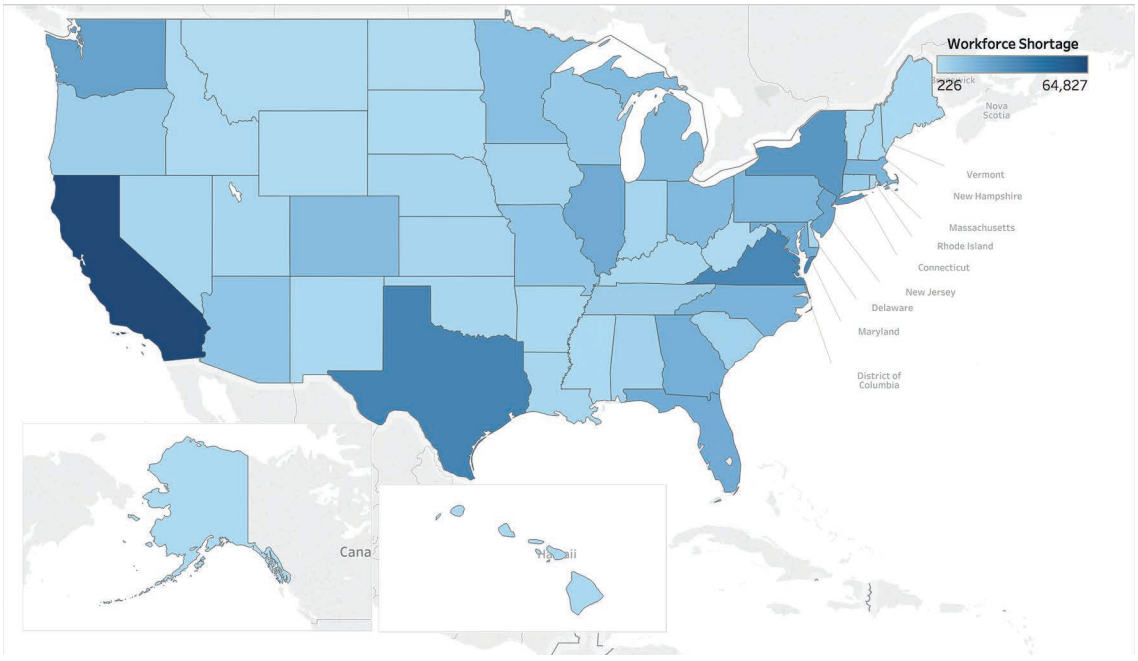

Figure 1. US map showing the workforce (person) shortage by state for jobs requiring computer science skills. Estimates project a deficit of 1 million unmet high-tech jobs in the United States alone by 2020.

projected to have a shortage in the high-tech sector similar to that in the United States.[3] This deficit is much more extreme in emerging countries that are depending on 21st century skill sets for economic growth.

Economics of Innovation

Innovation economics is an emerging theory emphasizing entrepreneurship and innovation as key indicators for a thriving economy.[4] In his book *The Difference*, Scott Page pointed out that the ability to see problems differently, not simply being smart, is oftentimes the key to innovative breakthroughs.[5] Thus, diversity among the problem solvers is more important to innovation than any one person's intellectual ability, suggesting that diversity in thought is integral to achieving innovation.[6]

Cultivating this diversity of thought necessarily means assembling a multicultural, diverse group of people to work as a team, leveraging what those studying organizational dynamics have known for some time. A team's ability to innovate requires the integration of different perspectives, knowledge, experiences, and backgrounds. This integration or intersection of seemingly unrelated perspectives is crucial to breaking through creative barriers. In fact, more diverse teams have tangible, measurable benefits to tech innovation. According to a University of Maryland and Columbia Business School joint study, gender diversity at the management level leads to a $42 million increase in the value of S&P firms. Additionally, the National Center for Women & Information Technology reported that 40 percent more patents were filed by mixed-sex teams than by all-male teams.

Diversity versus Inclusion

Workforce diversity reflects the factors used to differentiate people from one another. We typically think of workforce diversity in terms of race, ethnicity, religious affiliation, gender, and socioeconomic background. However, diversity can also refer to educational background, nationality, disability, age, sexual orientation, and a number of other factors we use to describe and understand the makeup of a population.

Diversity is 2D in nature—inherent and acquired. *Inherent diversity* reflects traits that individuals are born with, such as race and nationality. *Acquired diversity* reflects traits acquired from experiences over time. Both types of diversity are important to understand and cultivate.

Inclusion, on the other hand, reflects the quality of a group or person's experiences, referring to an individual's state of being valued, respected, and supported.

Thus, diversity and inclusion must be coupled. It is not enough to have one without the other, and both must be cultivated in the classroom, in teams, and in the workforce. Diversity is a direct reflection of recruiting from a broad talent pool. Successfully keeping and retaining diverse talent is a direct reflection of inclusion.

Predictions for Next-Generation Science

As technology matures, we are seeing an ever closer relationship between society, technology, and science and engineering brought to bear by our increasing need to understand the human condition, prevent human suffering, understand humanity's impact on our planet, and understand

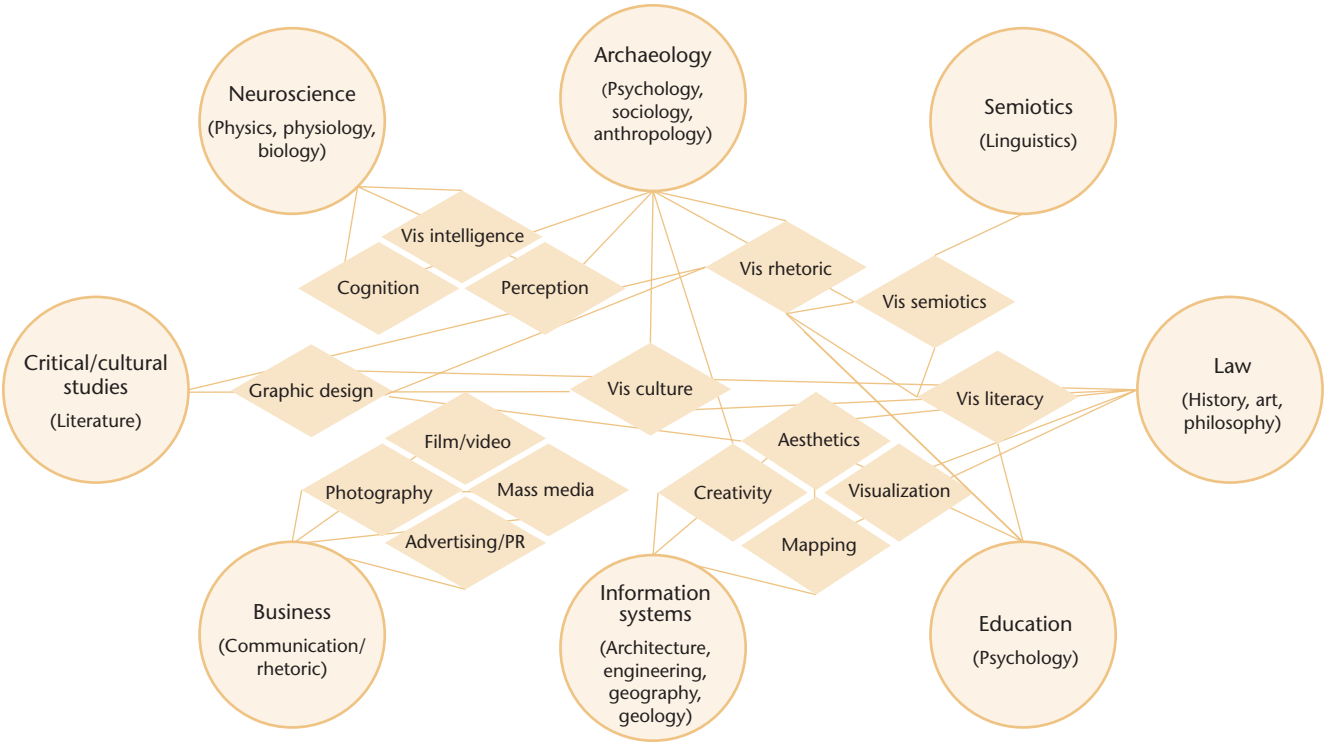

Figure 2. Inherent integration of visual tools for analysis and comprehension in basic and composite fields in science, humanities, law, and business. This graphical illustration was inspired by the rhizomatic map of visual communications by Sandra Moriarity and Gretchen Barbatsis.[9]

man's ever-changing stabilities and instabilities. There is no doubt that the relationship between these three are growing increasingly dependent upon one another.

Anthony Barnosky and his colleagues defined humanity's grand challenges for science and society as those solving the intertwined problems of human population growth and overconsumption, climate change, pollution, ecosystem destruction, disease spillovers, and extinction.[7] The solution space for these issues necessarily mandates interdisciplinary, collaborative R&D that fosters an active exchange of information and ideas.

Dictated by the need to solve larger and more complex problems, there is an increasing need for students and researchers capable of working productively in a multidisciplinary, collaborative environment. It is difficult to imagine working on problems of this magnitude in multidisciplinary teams with multicultural impact without thinking about how to communicate effectively. Visualization allows us to communicate, research, develop, and discover intersections that are key to new insights.

Visualization as a Universal Language

In Richard Gregory's book *Eye and Brain: The Psychology of Seeing*, he wrote, "We are so familiar with seeing that it takes a leap of imagination to realize that there are problems to be solved."[8] That is, we humans are inherently wired to process and visually assess the world around us. Our ability to see complex problems provides us a unique ability to understand things from a different perspective. It is this inherent ability to think about problem solving visually, particularly in a diverse team, that is the key to breakthrough discovery.[9]

In the *Handbook of Visual Communication*, Sandra Moriarty and Gretchen Barbatsis laid out a rhizomatic map of visual communications as a connected graph of relevant disciplines that have historically contributed to basic and composite fields of science, humanities, business, and law.[9] As Figure 2 shows, this interdependency illustrates that visualization (or the need to communicate visually) is a vital component in the development and understanding of a large and diverse portfolio of disciplines. Furthermore, it suggests that visual communication, digital or otherwise, provides a means of rapidly facilitating the understanding and development of theory and practicum across disciplines. Visuals let us communicate across cultural boundaries, identifying commonalities that can be a springboard for communication and collaboration. In "What Is the Shape of Thought?" Eileen Clegg and Bonnie DeVarco stated that "Visuals are the language of intuition."[10] This ability to make sense, imagine, and communicate across boundaries and barriers lends credence to the pre-

vailing thought that visualization has emerged as our modern day universal language.[11]

As technology advances and matures, we find ourselves in an increasingly digital world, oftentimes inundated with data. Given how inefficient our brains are at processing raw data, visual intervention or intermediate analytics are required to make sense of this growing mountain of data. Brain research tells us that humans only remember 10 percent of the information we hear, but we remember 65 percent if the information includes a picture. The human visual system is an inefficient text and aural processor, but it is excellent at synthesizing and understanding imagery. Our brain sees words as a lot of tiny pictures, requiring us to translate features in letters in order to read them.[12,13]

Computational thinking is a 21st century skill that is rapidly growing in value, but most students struggle with the concept, and it is not well understood. Several educators have used visualization to teach complex computational material with good success.[14,15] The research basis for the usefulness of utilizing visualization to understand abstract concepts is rooted in Allan Paivio's dual-coding theory. By creating visualizations, we tap into both the verbal and visual-spatial representational systems, making abstract concepts more concrete and thus more meaningful and memorable.[16]

The Visualization Community

As visualization researchers, developers, practitioners, and educators, we sit at the intersection of data, science, engineering, and insight. We are well versed in visual communication and operate fluidly as bridge builders between disciplines and technology. Our careers have been forged with the knowledge that communication is key, collaboration is vital, interdisciplinary is the future, and problems are getting larger and more complicated. Working in this intersection space provides us with a unique perspective, one that can and should be brought to bear as we broaden and diversify our community moving forward.

We Are Boundary Spanners

Social science defines *boundary spanners* as the agents in a collaborative setting who have a dedicated position and role to operate in a collaborative environment. These individuals operate in an environment in which reality is framed in different ways, depending on disciplinary backgrounds, organizational roles, and stakeholder needs. Boundary spanners are particularly important to have in interdisciplinary, collaborative teams because they can create representations that allow people from different stakeholder communities to communicate and work closely together to further a common goal.[17]

As researchers, developers, and practitioners in visualization, we operate natively as boundary spanners, oftentimes acting as connectors between disciplines, technology, and insight. Our natural training and ability to operate at these boundaries and communicate across boundaries provides a unique opportunity to be enormously effective in interdisciplinary research at the cutting edge of discovery and insight.

We Are Native Interdisciplinary Thinkers

Interdisciplinary studies require the ability to synthesize and integrate knowledge or thinking from two or more disciplines to create methodologies, theories, and products that further the understanding of the world around us. By definition, visualization is the process of synthesizing data, knowledge (heuristic, quantitative, or qualitative), methods, and technology to bridge the gap between data and insight. Visualization is often the common language with which a group of diverse researchers communicates and brainstorms. We rely on our ability to picture complex structures, see abstractions, and communicate through imagery that connects different groups through common biology, bandwidth, and capability in our visual cortex.

Where Do We Begin?

Creativity is fundamental to what we do as a community, as without it we would not be successful. It seems hard to imagine that visualization practitioners have not yet realized that our inherent and acquired diversity has placed us in a unique position to address the looming global workforce crisis. Because we work at the intersection, not in spite of it, we bring a much needed perspective on building and maintaining a community that is more in line with our respective national populations. Now is the time to understand what we can and should do and to commit to making diversity and inclusion a priority in our community moving forward.

Make It a Priority

A number of diversity/inclusion initiatives have been implemented to date. The high-tech industry has recognized the need to better understand how to recruit and retain diverse employees. Google, Amazon, and Microsoft, among others, have diversity programs in place and publish their diversity numbers in an effort to be transparent and pledge their commitment. In 2015, Intel pledged

$300 million to its Diversity in Technology initiative to train and recruit women and underrepresented minorities with the goal of achieving full representation by 2020. Many of the larger academic computing centers count and publish their numbers and have made public commitments to recruiting and retaining a diverse workforce.

The visualization community should be no different. We must count and publish our diversity data and pledge our commitment to be more diverse and inclusive. As a community, this means that we must ask our conference attendees to self-report race, ethnicity, gender, and age information, and we must publish this data annually. As members of the visualization community, we must initiate and support efforts at our local institutions to do the same.

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Teach and Engage the Why First

Neuroscience has discovered that the brain is wired to organize, retain, and access information through stories.[18,19] Teaching through story aids memory, provides building blocks for learning, and encourages imagination.[20,21] Storytelling also puts information into an emotional context, and emotions play an essential role in both memory and motivation. When emotions are present, hormones released to the brain act as a memory fixative. Story shapes life values and teaches acceptance, and it gives students an opportunity to broaden their understanding of heritage and culture, both theirs and others.

As a community, visualization researchers spend their careers thinking about how to solve a cadre of issues that can be roughly placed into a few key bins: design, delivery, comprehension, and usability. In short, a great deal of time is spent thinking about, discussing, and improving issues related to the how, but very little time is spent understanding the complexities of the why—or in other words, the motivation.

The how-centric approach for teaching visualization was mandatory in terms of the origin, care, and feeding of visualization as a field of science. Significant debate has occurred over the last two decades regarding the purpose, health, and longevity of visualization as a viable field. As a result, the visualization community is divided into those of us who believe there is little left to discover and those of us who believe we don't yet know what we don't yet know.

Our current student population, made up primarily of millennials and postmillennials, are the largest and most diverse sector of the population. These two generations have grown up in an age of pervasive and ubiquitous technology, violence, and information overload. Nevertheless, they tend to place great value on the role they play in their communities, including close relationships with their families, and they rate quality of life as important and express a strong desire to make a positive impact on their communities and society at large.[22] Tapping into their inherent desire to make a difference provides a critical motivational foundation on which we can teach next-generation computational skills. It is imperative that we as a community speak to this motivation or the "why" to ensure that we broaden participation and bring together a multicultural, diverse group of students who will form our next generation of researchers, educators, developers, and practitioners. Teaching visualization by introducing the "why" first taps into the benefits of storytelling. It encourages our students to connect information to an emotional context and provides a memorable mental framework for more abstract concepts and methodologies.

Engage Colleagues Specializing in Broadening Participation

A number of organizations specialize in broadening participation through initiatives, recruiting materials, tips for retention, and curriculum ideas. We should deeply engage those at our respective institutions whose job it is to broaden participation, and leverage the large body of knowledge gained over time in the national organizations. Here is a small sample:

- Founded in 2004 by Lucy Sanders, Bobby Schnabel, and Telle Whitney, the National Center for Women & Information Technology (NCWIT) has a number of initiatives to empower change leaders and increase women's participation in computer science.[23]
- In 1993, ACM formed a Women in Computing Committee (ACM-W, women.acm.org). In 2009, the committee was renamed the ACM Council on Women in Computing and dedicated to recruiting, retaining, supporting, and celebrating women in computing.

- The Anita Borg Institute (anitaborg.org) provides support for women in computing and technology through engagement with academic and corporate communities, helping them understand how to improve their recruitment and retention of women in computing and technology.
- Founded in 2003, the Institute for Broadening Participation: Pathways to Science (pathwaystoscience.org) focused on broadening participation and increasing diversity in the STEM workforce. It provides faculty and administrators with tools and resources to help promote the positive factors that keep STEM undergraduates engaged and on the path to a STEM degree.

Other organizations such as IEEE and the Computing Research Association (CRA) have also developed initiatives. Additionally, there are a number of partnerships and corporate initiatives through Intel and Google,[24] just to name a few.

In her 2006 speech to the Securities and Exchange Commission, President Shirley Ann Jackson of Rensselaer Polytechnic Institute closed with this: "Innovation, and the development and exploitation of new technologies require people, bright, talented, inspired, engaged, highly educated people who, of necessity, must be drawn from the complete talent pool, including from our new majority... This means we must ... [make] sure that the entire new majority is educated, prepared for advanced scholarship, encouraged, and mentored."

Diversity and inclusion are vital to innovation, and innovation is vital to a thriving technological economy. As members of the visualization community, we must recognize the benefits of a fully diverse, inclusive culture that marries what we know in visualization, what we see as future grand challenge science problems, and what we know is a looming crisis in the global high-tech workforce. We have a unique opportunity to engage our current and future student populations, helping them bring their skills to bear on problems of societal relevance. We can teach them to work well in multidisciplinary, multicultural team environments while maintaining a learning and working culture that is inclusive and fosters learning. We must encourage "speak up" environments from all members of our prospective community, ensuring that we welcome all good ideas. We must focus on teaching the "why" to engage our underrepresented populations.

We know that diverse teams directly translate to innovative teams and that innovation is key to economic competitiveness. We know that visualizations play a critical role in understanding and communicating complex phenomena, particularly among a diverse group of stakeholders. We know that our inherent ability as interdisciplinary thinkers and bridge builders puts us in a unique intersection space, where diversity in thought and approach is celebrated and encouraged.

As a community, we have a responsibility to bring a fresh perspective that fosters diversity and inclusion, but we are at a crossroads. We must make diversity and inclusion part of our fundamental fabric by making it a priority. We will certainly reap the rewards with greater innovation, more diverse thought, and a richer, more creative set of methods, tools, and products.

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