A PERSONAL VIEW

Motion sickness as metaphor: engaging with diversity in STEM

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INTRODUCTION

We are in the midst of a cultural shift in the fields of science, technology, engineering, and math (STEM), where we recognize a need to increase diversity and access to education and research benefits and are actively working to implement change across disciplines. Rebuilding STEM as truly inclusive to all people and identities requires far more than simply increasing the number of women and underrepresented minorities (URM) in our classrooms and laboratories; we must also consider how the structures and histories of STEM establish patterns of expectations for what it “looks like” to be a scientist, and how we respond when these structures and histories are challenged by our experiences working to increase diversity in STEM.

STEM, especially the STEM subfields of the natural and physical sciences, engineering, math, and computer science, have been historically and continue to be, to some extent, populated by white men at the highest levels of academia and in the workforce (31). The complicated structures and histories of STEM have been strongly influenced by this majority, as evidenced by the outcomes of the “draw a scientist” test (DAST) (1, 8, 10, 15, 16, 18, 29, 30, 36, 37). In this test, children were asked to draw pictures of scientists; for decades starting in 1950 and through to the early 2000s, children drew their scientists as predominantly white and male. The DAST is just one example that highlights a pervasive stereotype that the people who do the work of science are white and male, among other traits. This cultural identity of scientist as white and male also signals a much more subtle condition, that is, that to be a scientist requires one to assimilate into the behaviors, culture, and practices of the dominant majority identity, i.e., white and male (3, 5, 13, 28, 29). We see this further played out as STEM recreates and reinvigorates itself through ever decreasing diversity as people move through academic ranks (bachelor’s vs. graduate degrees vs. instructor and tenure-level appointments) (31) and as underrepresented students struggle to reconcile their multiple identities (race, gender, culture) with that of science (5, 13, 27). Combined with a culture of objectivity that strives to remove the identity of the scientist from the practice and outcomes of science itself (28), this signals that to be a successful scientist requires assimilation into the dominant (and, therefore, default) identity (3, 5).

The effects of these histories and structures can, in part, be measured. As scientists, it is perhaps simplest to first understand the problem of unequal representation in STEM according to the numbers. We can and do routinely measure the inequality of representation in STEM in the US. The National Science Foundation reports regularly on the status of women, minorities, and persons with disabilities in STEM. Although the statistics are not all bleak, a significant gap in representation does exist. Since 1995, there has been an increase in the number of STEM-related undergraduate degrees earned by URM (black or African Americans, Hispanics, and American Indians or Native Alaskans), especially in the areas of the biological and psychological sciences (31). Still, the racial and ethnic diversity of the broader population is not adequately reflected in the number of doctoral degrees granted or in the broader STEM workforce. Of the 38,939 doctoral degrees related to science and engineering earned in the US in 2014 (the most recent year reported), only 8% were granted to URM, yet URM comprise 29.5% of the US population between 25 and 65 yr [the age range in which the majority of doctoral degrees are granted (31)]. Similarly, blacks and African Americans make up 12% of the general US workforce but only 5% of the STEM workforce; Hispanics are 16% of the general and 6% of the STEM workforce (31). Clearly, we still have work to do if we believe that representation matters and that progress...
in STEM can benefit from diversity and equal representation of the broader population.

Science Identity

Science identity describes how people think of themselves and their identity as a scientist (5), and the development of a strong science identity is associated with persistence in STEM (9, 30, 31). Science identity is often analyzed in the context of an individual’s perspective, that is, how individual people view themselves in terms of their ability (competence and performance) to do the work of science and to assimilate into and be recognized by oneself and other scientists as a scientist (recognition) (5). Identity in general and science identity specifically are not, however, merely a personal choice and are heavily shaped by cultural and social cues. In other words, to fully claim a science identity requires participation with and recognition by a group of scientists (5, 27); denial of such recognition by other scientists may be a negative factor for development of science identity and persistence in STEM (28). This recognition or lack thereof can carry forward to include features of identity such as race and gender that may clash with the dominant categories, where women and non-white scientists may find it more difficult to assimilate into the white and male culture of science.

Using Metaphors to Understand Pushback Against Shifting Science Identities

We use metaphors throughout STEM to understand complex and abstract scientific concepts and principles, in large part because metaphors provide a reference point for organizing and assimilating new and abstract concepts. The conceptual metaphor theory by Lakoff and Johnson (22, 25) explains how the metaphors use the logic of a concrete bodily experience to describe, explain, or understand an abstract concept. This theory relies in large part on the concept of experientialism, wherein humans organize and understand their experiences in the context of their bodily sensations within an environment (25). Lakoff further embeds conceptual metaphor in a neural basis of information processing, whereby the structure and the computational functions of the brain drive our human capacity and affinity for the use of metaphors to explain abstract concepts (26). We frequently use metaphors in the classroom and laboratory to explain and understand complex subjects and scientific concepts, sometimes with mixed results (32, 40). This is, in part, because metaphors are necessarily incomplete to fully understand a concept (23). For example, neither of the metaphors “love is a journey” or “love is a burning fire” fully capture the essence of the abstract concept of love, yet both explain a portion of the experience of love in the context of two other experiences that many if not most humans have experienced, that is, traveling a distance to arrive at a destination and the heat of an open flame. Love is, therefore, explained as both a process and a feeling through separate but not conflicting metaphors. Nevertheless, Lakoff and Johnson argue that the use of conceptual metaphor is critical to scientific thought and experience, as “without [metaphor] we could understand very little beyond our direct physical experience” (23).

Here I describe a novel metaphor to begin to understand how and why we may experience discomfort as our internal models of identity in STEM are challenged. I developed a neuroscience-based metaphor based on a mismatch of the historical science identity with our drive to increase diversity in STEM, where this mismatch of expected and emerging science identities is like the sensory mismatch associated with motion sickness. Importantly, this metaphor can also serve to explain that adaptation and change can be effected over time, a framework that consequently provided me with the patience required to honestly and critically engage with my own concept and understanding of scientific identity and how it manifests in my interactions with students, mentees, and colleagues as we work to rebuild STEM as radically inclusive. I encourage the careful evaluation of models and mechanisms within STEM disciplines as metaphors to start deeper conversations about the challenges and rewards of redeveloping STEM education as inclusive and welcoming to all students.

Building the Metaphor: the Bodily Experience of Motion Sickness Is the Result of a Sensory Mismatch Between Visual and Vestibular Systems

Motion sickness is an ancient and shared bodily experience, with textual evidence of its existence as early as the Greek physician Hippocrates. He wrote, “sailing on the seas proves that motion disorders the body” (2). The nausea and discomfort associated with being a passenger in a moving vehicle or a boat on the water are a familiar and noxious experience for those who are susceptible. A leading and enduring theory on the etiology of motion sickness, the neural mismatch model proposed by Reason and Brand in 1978, is that symptoms of motion sickness (nausea, vomiting, dizziness, pallor, sweating, among others) arise in response to a mismatch between the sensory input of the visual system (eyes, for sight and visual information) compared with the sensory input of the vestibular system (inner ear organs, for head position and movement of the head relative to gravity) (2, 34, 35).

According to the sensory mismatch model, motion sickness can be described as the result of normal sensory processing in an abnormal situation. Under normal conditions of self-propelled movement (walking, running, turning the head), information from the visual and vestibular (inner ear) systems is processed in the brain to ensure that the eyes stay focused on a spot while the head and body move in space (6, 42). This processing and integration of information from separate sensory systems is accomplished through a constant comparison of the visual and vestibular inputs in the brain stem and cerebellum. The brain processes this information to create an internal correlative model over time, where a specific type of visual cue is associated with a specific type of vestibular (inner ear) stimulus, and vice versa. This establishes a matching of the sensory inputs as an internal neurological model of the experience of movement through space. The internal neurological model is always on, meaning that all inputs from the eyes and inner ear are constantly being compared with one another with the expectation that they will match one another according to the model.

Sensory mismatch occurs when the head movement does not match the visual cue or vice versa; this is why people can develop the symptoms of motion sickness while in a moving vehicle or during the illusion of movement while sitting still and viewing a 3D movie or virtual reality. In these settings, the visual experience may be associated with a movement of
one type, while the vestibular input to the brain would predict movement or head position of a completely different type. These inputs are compared with the internal model of movement through space, the expectations of sensory matching in the brain are found to be in conflict with one another and the model, and the outcome is nausea and other symptoms of discomfort. In the simplest terms, the experience of movement under these conditions does not match the expectation of what normal movement should be, and motion sickness results.

Importantly, the sensory match model related to motion sickness is a model that is developed through and shaped by prior experience. In development and throughout life, experience shapes and refines the architecture of the brain, and the visual and vestibular pathways are no different. Although the initial neurological connections between the organs of the visual (eyes) and the vestibular (semicircular canals and the utricle and saccule) systems and the brain are determined by genetic programs during development, axonal pruning and synaptic strengthening and weakening due to processing of sensory information shapes the type of information that ultimately reaches the primary processing centers of the brain for this type of information. Similarly, while higher order processing of this information beyond the primary processing cortices is initially processed through the genetically determined connections between areas within and between the cortex, cerebellum, and brain stem, each experience of new information shapes and refines the circuits of processing, which ultimately leads to the prevalence of an internal, neurological model of movement through space that is based on the integration of input from multiple sensory systems.

Building the Metaphor: the Abstract Concept of Changing Science Identities

So what, if anything, does the sensory mismatch model of motion sickness have to do with race, gender, and identity in the context of STEM and science identity? The key connection is the prior, embedded internal model of expectations of the canonical (white, male) science identity already in place and the dissonance that arises when we experience new categories and types of people who can and do develop and claim a science identity.

STEM has been historically and still, in large part, dominated by white men, which establishes and maintains an internal model and set of expectations that the people who are doing the work of STEM are and will be primarily white and male. This model and set of expectations is based in large part on a disciplinary history, where the achievements of white men have defined and set in motion decades and even centuries of research agendas. This history is thus partially responsible for establishing the structures by which success is measured, complicating for some the recognition of success in STEM (5, 20, 28). The established structures set expectations for what it “looks like” to be a scientist, and these expectations are reinforced by the current state (or experience) of many STEM subdisciplines, which remain predominantly white and male (31). Regardless of our overt or implicit acceptance of this model of science identity, it is true that performing like a white male is, in some ways, necessary to navigate and receive recognition within the field of STEM, and that we know what kind of environment, colleagues, and interactions to expect when we attend classes and conferences or approach new jobs and research opportunities (5, 27).

This internal model or expectation of science identity as white and male is tested regularly against experience in the classroom, laboratory, job setting, popular culture, and news media. The danger of the model, though, is that it may, by being the implicit standard against which all scientists are in part measured, lead to pushback and bias against individual people and against diversity and inclusion in STEM (21). Model mismatch, for example the inclusion of black and African American women in science, can lead to an unconscious sense of dissonance for people who subscribe to the historical model, which might also be called implicit bias (17). This dissonance or bias can be overtly, yet still unconsciously, acted upon. Examples of the negative experiences of women and people of color in STEM fields abound, from the seemingly innocuous [being left out of discussions for abstract or article submission, a lack of response to email or other correspondence, or other ways of being made to feel invisible (28)] to openly hostile (openly questioning the validity of the success, attributing it to cheating or “riding on the coattails” of colleagues, dismissing or feminizing the fields of inquiry in which the most prominent workers are women or people of color, or arguing that affirmative action is the only reason for access to STEM spaces).

Put simply, the metaphor is that this mismatch of expectations (STEM as stereotypical white and male space) and experience (not everyone in STEM is actually white or male) is akin to the mismatch of expectations and experience (vestibular and visual inputs) of motion sickness. The internal model that is meant to help us understand and be comfortable with the white male space of STEM is challenged when we experience other people (women, URM students, people with disabilities) succeeding in that space. Like the internal model of self-propelled motion through space that leads to noxious physical symptoms when challenged by motion in a car or on a boat, our internal model of STEM as a white space, the model that, in part, structures how we act in STEM spaces and places (5), establishes expectations that, when challenged by individuals who do not subscribe or adhere to the established model, potentially leads to cognitive disorientation and discomfort.

The caveats of this metaphor, like all other metaphors, are myriad. Although motion sickness is a shared experience of many people, it is not wholly universal to all people. Similarly, a sense of discomfort or disorientation in the midst of shifting science identities is not experienced by everyone who engages with the field of STEM and STEM education. Still, just as incomplete scientific model systems are useful for exploring universal themes of STEM, this metaphor presents the opportunity to investigate, engage with, and begin to understand an abstract concept, that is, responses to changing science identity in an ever-diversifying field. For instance, the mechanism of motion sickness and adaptation (developing of “sea legs,” for instance) provides an additional metaphor to understand that an initial discomforting response to increasing diversity in STEM and STEM education is not permanent.
Land Sickness and Awakening: Taking the Metaphor to the Next Step

There is no pharmaceutical cure for motion sickness. In fact, the best way to treat motion sickness is to remove oneself from the situation that is causing the symptoms: get out of the car, get off the boat, or leave the movie theater. The standard historical “treatment” of the model mismatch in STEM is metaphorically similar; we continue to argue for more diversity in STEM while maintaining practices throughout the field that overtly and covertly limit the inclusion of women and URMs (28). Thus we effectively remove ourselves from experiencing a mismatch between the historical understanding of science identity and any potential dissonant updates; whether consciously or unconsciously, we get off the diversity boat. However, the metaphor of motion sickness offers a chance to discuss some solutions.

Getting off of the boat is not the only way to resolve seasickness. As generations of seafarers have experienced, it is possible, over time, to adapt or habituate to the conditions that initially caused motion sickness. Adaptation in motion sickness requires extensive exposure to the mismatch, because the internal model that compares the two sensory inputs (visual and vestibular) must recalibrate to the new “normal” sensory match. In other words, new experience is incorporated into the internal model to change the expectation of what normal movement through space should look and feel like. Interestingly, this recalibration or habituation is durable enough that it can lead to the phenomenon of “mal de débarquement” or “land sickness,” where the sailor experiences the symptoms of motion sickness while on land because the sensory inputs of walking on land are in conflict with the revised internal model of being on the ocean (7). But the adaptation associated with prolonged exposure to sensory mismatch is not perfectly durable in all cases [although pathological mal de débarquement has been noted (7)], and sailors do eventually rehabilitate or adapt to motion on land without the associated sickness.

Similarly, it is possible to experience a lifting of the veil, or an awakening, as W. E. B. Du Bois called it (13), to the problematic default science identity. In this case, one might find oneself somewhat disoriented, not by increasing diversity, but rather by spaces and structures that strive to maintain the white and male identity characteristics. In other words, even with the challenge of complex societal, historical, and educational cues, as STEM becomes more diverse, the internal model or expectation of science identity can likewise be updated through experience, and the new science identity can serve as the expectation against which all experience is measured. Indeed, the results of a new meta-analysis of more than 20,000 DASTs from US K–12 students collected between the 1960s and 2015 showed an increase in the representation of female-presenting scientists in student drawings (30). The authors of this study suggest that this increase may be the result of a concurrent increase in the visible participation of women in STEM, even though the degree of increase over time in drawings does not adequately represent the real-world increase (30). There are trends of increasing diversity among recipients of bachelor’s degrees in biological, psychological, and social sciences since 1995 (31). Through these examples, we see that the cultural understanding of science identity is shifting to be, at least incrementally, inclusive of some nonwhite and nonmale identities. This progress is to be celebrated, but we must also be conscious and critical of the ways in which we participate in and respond to this work.

Especially within STEM, we must be conscious of how we approach supporting a change in science identity. The literature on developing science identity, including in-depth focus group studies and reports of the experiences of women and URMs in STEM reveal a distinct struggle and unequal burden carried by these STEM trainees within their fields as they are developing their identities as scientists (33). Science identity plays a role in persistence in STEM (9, 38, 39), and recognition and validation by the broader field is an integral part of the development and stabilization of a person’s science identity (5). Thus the broader STEM field must take an active role in supporting and validating the development of a strong science identity in new scientists.

However, if the dominant identity historically associated with STEM is white and male, we must be aware of how we may unintentionally drive students who do not claim that identity to feel as if they must assimilate to stereotypically white and male characteristics to be a scientist, while perhaps leaving their other identities behind (3, 19, 28). Students who do not subscribe to this assimilation strategy may not feel as if they belong in the field and may, therefore, leave. Furthermore, the science identity of educators and mentors may also be rooted in this same potentially problematic white, male-centric historical identity of science, thereby perpetuating the problem for their students and mentees. Thus we as educators and mentors must update our expectations for and mentoring strategies around who we believe can succeed in STEM. This includes understanding not only different motivations among women and URMs for choosing STEM careers than their white and male peers, such as personal interest, a desire to work with others, and working in a career that cooperates toward a communal goal (3, 11, 12). We should also shift from, or at least critically evaluate the use of, the metaphor of a STEM “pipeline,” leaky or not, as it may indicate that there is but one way to establish oneself in the STEM field and does not adequately address the barriers to full participation by women and URMs, not the least of which is the continued perception of STEM as a male-dominated field. Instead, we can begin to think about pathways to STEM, many of which may be indirect, but all of which allow for multiple different avenues and strategies for arriving at a STEM education or career (4, 14). Finally, we must identify and address our conscious and unconscious biases about the culture and expectations of STEM, especially at the level of STEM education, and how these biases may change the ways in which we provide recognition and acknowledgment of developing science identities among our students (21). These approaches focus on revision of the culture of the fields of STEM to positively change the external recognition component of science identity, a key factor in the successful development of science identity that is out of the direct control of new scientists. These suggestions, therefore, place the burden of change on the field that wishes to embrace diversity rather than the new scientists that we hope to welcome through the push for increased diversity among our ranks.
Why Metaphors Matter

Cognitive science and the conceptual metaphor theory make the claim that our ability to reason and understand the abstract is bound to our physical body through our neuronal architecture (24). Through this framework, Lakoff and Johnson, argue that conceptual metaphors provide a structure on which we build our understanding of abstract and philosophical concepts. We rely on prototypes to establish a framework of reasoning through which we filter all other reasoning (24). In much the same way, we in STEM use model systems, pathways, and processes to investigate and understand universal concepts in our field. Although we recognize the immense power of these model systems, we also recognize their inherent limitations. In much the same way, we must recognize the power and limitations of conceptual metaphors and this neuroscience-based metaphor in particular.

Using metaphors based in bodily experience requires the assumption that all bodies exist with the same basic structures and functions. Although neuroscience would agree that most of the genetic-based patterning of the body in what would be called “normal” development is relatively similar across our species, we are also acutely aware of the individual variability of development due to genetic variability and environmental pressure. Thus the bodily experiences of one person may not adequately mirror that of another person, thereby limiting the utility of a conceptual metaphor for universal understanding of an abstract concept (41).

Science identity is an abstract concept, as are our internal reactions to shifting science identities. But metaphors, even incomplete metaphors, provide opportunities to explore and discuss these and other abstract concepts (22, 23, 26) as we engage with work to improve diversity in our fields. By acknowledging that there may be dissonance between our expectations for what it means to be a scientist and our experiences as our fields become more inclusive, we may begin to challenge our assumptions and biases in productive ways. This metaphor provides at least three opportunities for further engagement with the implications of increasing diversity within the STEM fields. First, it provides relevant language to explain a sense of dissonance that we might feel but may otherwise be unable to articulate. The metaphor, therefore, gives an opportunity to discuss what may be a shared experience, rather than dismissing or minimizing the impact of any disorientation we may experience at increasing diversity in STEM. Second, the metaphor can be used to explain this feeling and transition to people who may not have experienced either increasing diversity in STEM or any sense of unease or disorientation in the face of increasing diversity in STEM. It can start a conversation that may probe deeply into the roots of our understanding of what it means to be a scientist. And last, the metaphor can be used as a gateway to seek solutions, in this case suggesting that patience and perseverance in the face of increasing diversity in STEM. It either increasing diversity in STEM or any sense of unease or feeling and transition to people who may not have experienced STEM. Second, the metaphor can be used to explain this disorientation we may experience at increasing diversity in our understanding of what it means to be a scientist. And last, the metaphor can be used as a gateway to seek solutions, in this case suggesting that patience and perseverance in the face of increasing diversity in STEM. It also shapes how we approach this question of access to science, and leveraging that basic science training in new ways, like through this metaphor, can start the process of reflection and reevaluation of our practices, thus leading to real and important change in how we support building a more diverse and inclusive discipline.

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AUTHOR CONTRIBUTIONS

R.A.B. conception and design of research; drafted manuscript; edited and revised manuscript; approved final version of manuscript.

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