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Dark Matters: Metaphorical Black Holes that Affect Ethnic Underrepresentation in Engineering

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Dark Matters: Metaphorical Black Holes That Affect Ethnic Underrepresentation in Engineering

1.0 Introduction

Astronomers believe that at the center of every galaxy is a super-massive black hole. Planets, stars, and galactic objects ultimately orbit around this central black hole. Black holes are awe-inspiring structures whose existence and behavior are predicted by our current understanding of physics, however, they manifest extraordinary phenomena that stretch our understanding of the universe. The science in support of black holes requires the presence of matter that is, so far, unseen by scientists. This unseen matter and its energy is said to make up as much as 96% of the known universe. Dark matter, its structure and energy, explains how the universe works.

This paper will establish unique metaphors between social science and physics. The social science context also takes into account the social justice current events of the #BlackLivesMatter movement in the United States where social media brought to bear conversations about the injustices related to untimely deaths of unarmed African-Americans by those in law enforcement. The movement has elevated the conversation to a point where we can draw parallels to look at the academic lives of people from underrepresented groups, and the worth of these lives by academic power structures. As scientists and engineers, we bring the parallels of the current social justice events into a context that is being observed in the academic institutions: diversity in engineering. While social scientists have developed theories on the topic, we seek to further quanlify the observations by applying terms that have also been ascribed to the universe. We typically turn to nature and literal forces of the universe to understand phenomena, and to avoid catastrophe. The same can be done here, as we connect social justice to social science to episodes and events that occur in the universe. Specifically, we establish a metaphorical relationship between the institutions of higher education and the aspects of astrophysics. Our focus will be on dark matter and black holes. We liken an institution of higher education to a galaxy with strange and seemingly unknown dynamics where departments, faculty, staff, students are all in orbit about a central black hole. We discuss some of the unusual phenomena of black holes and relate these dynamics to observable physics of engineering departments.

Each of our institutions of higher education can be thought of as a galaxy with strange and seemingly unknown dynamics where departments, faculty, staff, students are all in orbit. There are some dynamics that are well understood, however, there is also unseen material and energy that causes some institutions to succeed while others fail. With respect to including people from all backgrounds in STEM education, and particularly engineering education, there are large disparities that are affecting the orbit. Decades of research in the recruitment and retention of ethnic minorities in engineering has resulted in an understanding of the ‘physics’ of engineering education pipeline. The statistics from the 2013 Survey of Doctoral Recipients show that out of

150,600 people in the U.S. who currently have doctorates in engineering, only 7,500 (4.9%) are from Hispanic, African-American, and Native American backgrounds - groups that are underrepresented in engineering according to the National Science Foundation. These same groups as a whole, represent 31.8% of the U.S. population according to 2014 U.S. Census statistics, demonstrating a strong need for increased efforts in both recruitment and retention in order to achieve parity.[22, 23, 24] The discussion in this paper will examine real world orbits in the context of academic orbits, and an Alliances for Graduate Education and the Professoriate (AGEP) professional development program, sponsored by the National Science Foundation, that is designed to broaden participation in engineering and other STEM fields.

2.0 Real World Orbits

The word "orbit" often brings to mind the celestial phenomenon where massive objects such as planets, moons, and stars, seem to revolve around one another. Orbital mechanics is a complex mathematical discipline beyond the scope of our discussion in this work, however, we will highlight some key properties of real world orbits that are relevant to our metaphor.

Orbits are made possible by the force of attraction of between two objects, determined by their mass and their distance from one another known as gravity. The equation for the force of gravity between two objects is given by,

$$f_g = \frac{G \cdot M_1 \cdot M_2}{r^2} \tag{1}$$

where, M_1 and M_2 are the masses of Object 1 and Object 2 respectively. G is a gravitational constant, and r is the radial distance between the center of masses of the two objects.[25]

Equation 1 shows that the force of gravity increases with increasing mass of the either object, or decreasing distance between the objects. In the absence of any other force, two objects at rest will be attracted to one another and begin to move linearly towards each other until they collide.

Orbits, as we commonly observe them, are the result of the relative motion between objects under the force of gravity. Consider the case of a ball launched from a cannon as shown in Figure 1.1. In the absence of friction, the ball will follow an arc determined by the initial velocity of the object and the gravitational force between the projectile and the earth. The gravitational force pulls the ball back to the earth as shown in Figure 1.1. This well-known result from first year physics is the special case where the velocity and height of the object from the surface of the earth is sufficiently small, such that the gravitational force (f_g) on the object can be expressed as a constant, g, times the mass of the ball. In this case, the orbit of this projectile (the ball) will be brief, aloft above the earth for a short time before coming in contact with the ground.

At greater speeds and distances, the gravitational force between the earth and a projectile is better modeled by Equation 1. In this case, if launched at a sufficient angle of elevation and velocity, a ball will experience less gravity as it travels further from the surface of the earth. In the absence of any resistance, there exists a minimum velocity where the ball will continue to circle the earth and not return to the ground as shown in Figure 1.1. The velocity required for an object to achieve, for example, a low earth orbit is just over 17,400 miles per hour or 7.2 km/s. In practice, rockets are used accelerate to such speeds in order achieve an earth orbit. It is important to note that, even at such great speeds, the projectile is still falling back to the earth however, it is traveling so fast that it misses the earth each time. This is what we typically know as an orbit. The higher the gravitational force between the projectile and the earth, the faster the projectile must travel in order to maintain an orbit. The higher the orbit, the lower the gravitational force, and the lower the speed required to maintain the orbit (for the same mass).

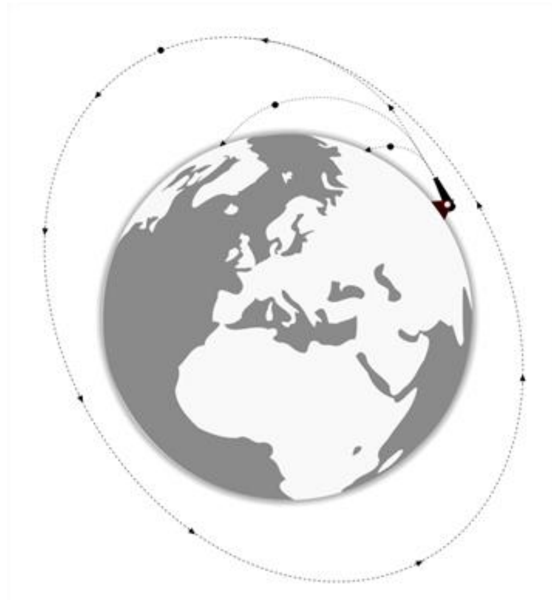

Figure 1.1: *In the absence of wind resistance, a projectile launched at sufficiently high speeds will orbit the earth. The object is still falling to the ground, except that its speed causes it to miss the earth on each pass.*

2.1 Maintaining Orbits

Practical objects, such as satellites orbiting large bodies like the earth, are subject to forces that can erode the speed, and thus change the velocity of the satellite which will cause it to fall out of orbit. For example, Figure 2.1 shows that at sufficient orbital velocity (V_{ORB}), although extremely thin, atmospheric drag (f_{DRAG}) can slow the speed of an orbiting object at altitudes as high as 370 miles (600 km) above the earth. Further, this form of drag can be greatly affected by the sun, which has energy and solar winds that can cause higher density air near the surface to rise into the upper atmosphere. Collisions with space debris also degrades the orbits of satellites. Debris fields may exert an intermittent force (f_{DEBRIS}) that opposes the momentum of the satellite, and causes orbit decay in a manner similar to atmospheric drag. The National Oceanographic and Atmospheric Administration (NOAA) identifies collisions with space debris as a major threat to space operations. Another force that can disrupt the orbit of an object (although not shown in the diagram) is the force of gravity caused by the sudden introduction of another massive object.

It is critical for a satellite to counteract the forces that can change its momentum in order to maintain its orbit. If the satellite slows down, gravity overcomes its momentum and draws the satellite to the surface. Once in orbit, on-board control systems use sensors to measure the attitude of the satellite. The control system then activates thrusters to adjust the velocity of the satellite and oppose the forces that threaten its assigned orbit. Failure of the sensors, control systems, or thrusters can lead to disaster.

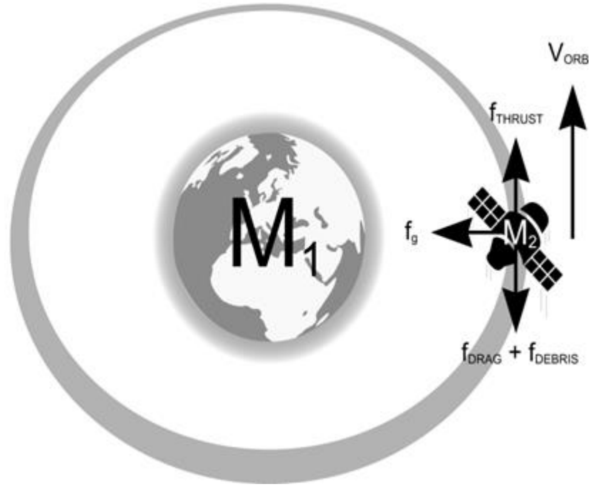

Figure 2.1: *Satellites must attain and maintain sufficient velocity in order to remain in a prescribed orbit. Opposing forces from drag (f_{DRAG}) and debris (f_{DEBRIS}) can cause the satellite to slow down and to be gradually drawn to the earth by gravity (f_g). In order to maintain their orbit, satellites must* ***actively*** *counter these opposing forces.*

2.2 Orbiting Black Holes

Black holes are mysterious and beautiful structures, formed by the collapse of a dying star as it implodes and concentrates its mass into such a small point, such that it creates a space-time singularity. This singularity distorts time and space so much, that even light falls into the black hole and cannot escape. Predicted by Einstein's theory of relativity, black holes come in different types. A detailed treatment of the solutions that represent black holes in Einstein's theory is beyond the scope of this paper. For the purpose of our discussion, unless otherwise noted, we focus the non-rotating, zero-charge, super-massive black hole, also known as a Schwarzschild black hole.

Black holes in general are more common and meaningful than we once knew. Physicists now believe that a super-massive black hole ranging in size from 500,000 to more than 30 billion miles across is at the center of every one the billions of observable galaxies in the universe, including our own Milky Way galaxy. Each galaxy is also expected to have numerous smaller black holes sprinkled throughout its span. Many astrophysicists have concluded that super-massive black holes are the origin of galaxies. Dr. Neil DeGrasse Tyson refers to super-massive black holes as "the seeds of galaxies."

Life is a little strange in and around a black hole. As shown in Figure 2.2, black holes are not vacuum cleaners that suck up everything in their vicinity. When a black hole is formed by the collapse of a star, the objects in orbit of the star before its collapse remain in orbit of the newly formed black hole. In this 'Quiet Region', the pre-collapse geodesics are preserved. Objects may even orbit the black hole structure in the region formerly occupied by the original star without consequence. However, once an object crosses the Event Horizon, no particle or light can escape the gravitational pull of the black hole. Since Einstein's general relativity states that nothing can travel faster than the speed of light, nothing inside the event horizon can cross this boundary and escape beyond, even light. Therefore, nothing that enters a black hole can get out or can be observed from outside the event horizon.[20] Objects crossing the Event Horizon will be inexorably drawn into the singularity where the tidal forces of gravity near the singularity will eventually stretch the object into a single stream of atoms in a process scientists call 'spaghettification'. It is further postulated that the gravity of the singularity is so great, that these atoms could disintegrate and disappear into the singularity. Another possibility is discussed later in this paper. Regardless of the ultimate outcome, there is no question, a decaying orbit into a black hole has terrible consequences.

Due to the extreme warping of time and space near a black hole, strange things happen. As an object approaches the black hole, inside the radius of the original star but before the event horizon, an outside observer would see the object slow down. However, the actual object is accelerating towards the black hole. When the object reaches the Event Horizon, to the outside observer, the object seems to come to a stop. At this moment, the observer is seeing the light from the object at the instant before the object enters the Event Horizon. The photons from this final 'snapshot' will be eventually be pulled away from the viewer into the black hole and the image will eventually fade away. Meanwhile, the object crosses the Event Horizon, any future light (and therefore events) related to that object are forever lost from view and consumed by the black hole. After crossing into the Event Horizon, in a matter of minutes or hours, the object will undergo spaghettification. As part of the setup for our metaphor to this point, we have discussed the effects of gravity on the orbits of objects. However, gravity is not the only the force holding celestial bodies in place. Physicists are aware of another even more influential force at work known as dark matter and dark energy.

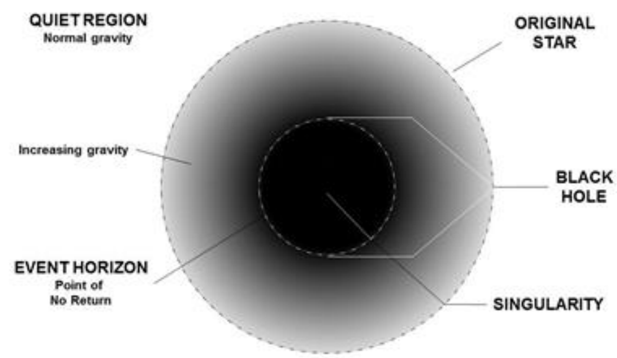

Figure 2.2: *Anatomy of a black hole. Outside of the radius of the original star is a quiet region of normal gravity. Inside this radius, gravity begins to increase quickly as one approaches the Event Horizon. At the Event Horizon, no light or matter can escape. Spaghettification occurs as one is drawn closer toward the singularity.*

2.3 Dark Matter and Dark Energy

Black holes are not directly observable since particles and electromagnetic radiation cannot escape the Event Horizon. Our only physical evidence of a black hole is based on the behavior of the visible matter surrounding them. Fortunately, space telescopes can observe the behavior of material and stars that are very close to black holes.[2, 9] This is a property of a large class of unseen objects in the universe astrophysicists call dark matter. Astronomers in the 1920's measured the rotation and the mass of the visible stars and planets in galaxies and realized that there isn't enough mass to account for the structure of the galaxies. Originally called 'missing mass', physicists have since hypothesized that there must be a massive, invisible form of matter that is influencing arrangement of the visible matter in the universe. This mass today known as dark matter. Dark matter and its associated dark energy has been estimated to represent 96% of the mass of the universe. Dark matter possesses the following properties: 1) It is invisible; it does not emit electromagnetic radiation; 2) It only interacts with visible matter through gravity; 3) It is slow moving.

The actual substance of dark matter is the subject of debate, however, according to National Aeronautics and Space Administration (NASA), there are two potential candidates: MACHOs and WIMPs. Massive Compact Halo Objects (MACHOs) are highly dense objects made of ordinary matter (i.e., protons and neutrons) in the form of failed stars known as brown dwarfs and imploded (neutron) stars, and black holes. Weakly Interacting Massive Particles (WIMPs) – subatomic particles not made of ordinary matter, theoretical candidates include neutrinos, axions, and neutralinos. The mass of these particles are extremely small but exist in such large quantities the gravity from their mass influences the structure of galaxies.[6] The consensus among scientists is that there aren't enough MACHOs to account for all of the dark matter in the universe but they contribute to local structure. WIMPs, however, are the leading theoretical candidates for dark matter. Estimated to account for nearly 23% of all matter in the universe, dark matter affects the motion of galaxies, bends the path of light and influences the structure of the entire cosmos. We know very little about the nature of WIMPs except that they were formed shortly after the Big Bang and they are heavy (massive) and slow-moving enough to gravitationally clump together and form structures observed in today's universe. Physicists predict that dark matter is made of these particles. However that assumption is based on what they know about the nature of regular matter, which makes up only about 5% of the universe.[3]

According to Einstein, mass and energy are interchangeable. Dark matter has a counterpart known as dark energy. Dark energy is believed to be responsible for the distribution of galaxies in space and the observed accelerating expansion of the universe. A detailed treatment of dark energy is beyond the scope of this paper. However, it is important to understand that while dark matter is responsible for the structure of galaxies, dark energy is responsible for the structure of the universe. The scale and importance of dark matter and dark energy cannot be understated. Dark matter and dark energy represent 96% of the substance of the universe.[26]

3.0 Academic Orbits

Orbits surrounding engineering departments can have negative effects on diverse scholars which present challenges to broadening participation in engineering. Academic orbits often manifest additional opposing forces that impede the orbit of otherwise potentially successful students and future faculty. In the following, we explore these dynamics terms of an astrophysics metaphor using the concepts developed in the previous section on Real World Orbits.

Our metaphor begins with the typical college of engineering as shown in Figure 3.1. The college is modelled as a spiral galaxy with a super-massive black hole at its center. All of its departments, including for example, Electrical and Computer Engineering, Civil and Environmental Engineering, Industrial Engineering, Mechanical Engineering, Biomedical Engineering and Chemical Engineering all orbit the College of Engineering black hole. This structure is held together by the invisible yet massive gravitational force of Dark Matter. Each engineering department (system) has its own black hole where all of the elements of the department process in orbit, as shown in Figure 3.2. The department chair, senior and junior faculty, staff, students, courses, new and mature research programs, federally research centers are all in orbit around the departmental black hole. Figure 3.2 also illustrates a damaged research program and a struggling student and junior faculty member. This is a crowded orbit. In close orbit to the black hole are the department chair and senior and 'star' faculty who, during the course of their careers, have developed enough momentum and skill to withstand the gravitational forces and opposing forces in this orbit and to assist others in theirs. As in the case of many galaxies including our own Milky Way, the center of a system is often the most 'luminous.' In the second outer orbit, all of the day to day operations occur, for example, teaching and learning, research, and interpersonal interactions. There are dynamics in every orbit. For the purpose of this paper, we will focus our attention on this outermost orbit.

An academic orbit in this metaphor is the velocity and path required to attain academic progression or advancement goals without succumbing to the central force of gravity (e.g., the dynamics of the engineering department.) Whether a student in a class or a faculty member pursuing tenure there will be drag, opposing forces that can impede progress along this path. The drag encountered by diverse scholars associated with micro-aggressions and implicit bias occur in this outer orbit. This drag is in addition to the technical drag of an engineering program and can cause the most talented diverse student or faculty member to fall out of orbit and toward the departmental black hole. Since drag is inevitable, drift is the greatest enemy to those in academic orbits. As discussed in Section 2. Real World Orbits, artificial satellites have on board control systems to fire thrusters when drift from the scheduled orbit is detected. Students and new faculty are rarely knowledgeable about the baseline orbital dynamics of their department so they often drift imperceptibly towards danger.

When departments ignore this drag, it can result in inadequate mentoring that can cause graduate students to leave engineering degree programs and faculty to leave their departments (even after tenure). Drag must be overcome proactively with corrective measures described later in this paper. The effectiveness of these approaches are influenced by cultures within departments or colleges, under the leadership of chairs and deans respectively.

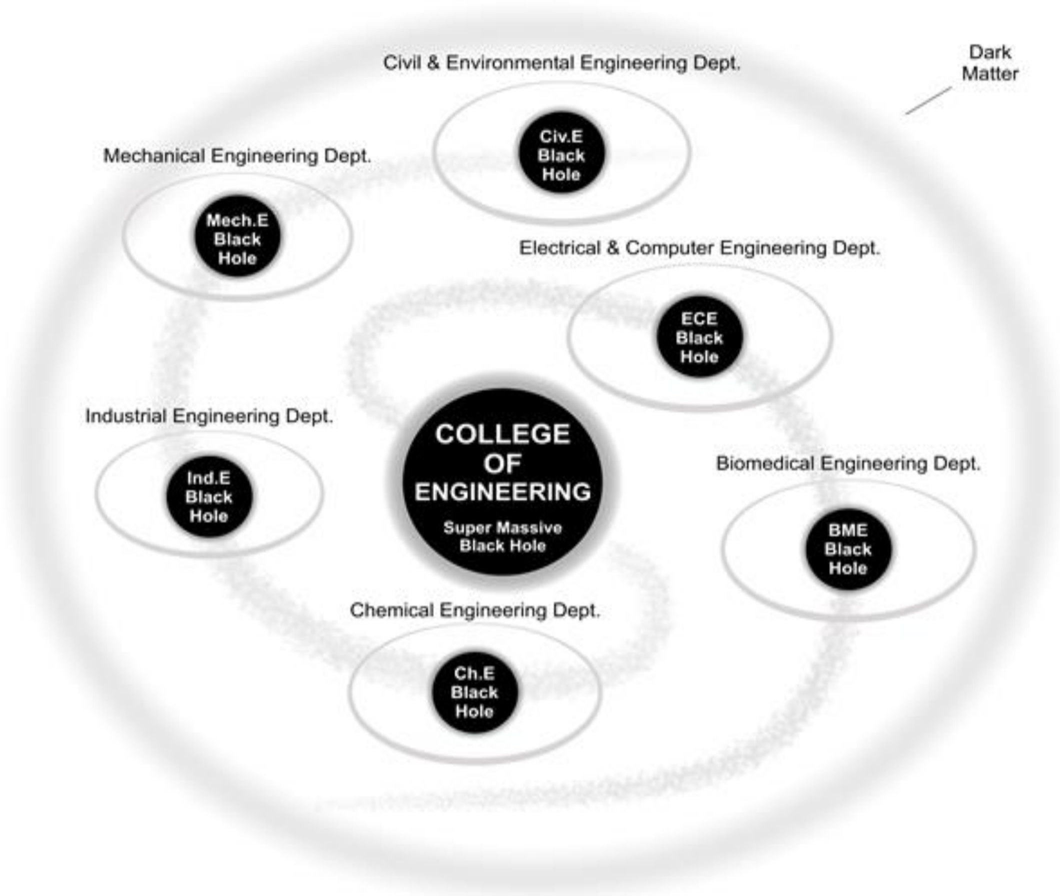

Figure 3.1: *A typical College of Engineering can be thought of as a galaxy with a central super-massive black hole and each department as a system with its own local black hole about which the elements of each department process in orbit. The gravity of invisible dark matter (shown) supports the structure of this galaxy.*

At the center of every academic department, there is a black hole. Once a person has completed the involuntary trajectory into the organization's black hole, the process of destruction has begun.

3.1 Academic Gravity

In our academic galaxy metaphor, gravity or gravitational pull takes on a new meaning. A student or new faculty member selects an institution because they seek to become (a graduate, a

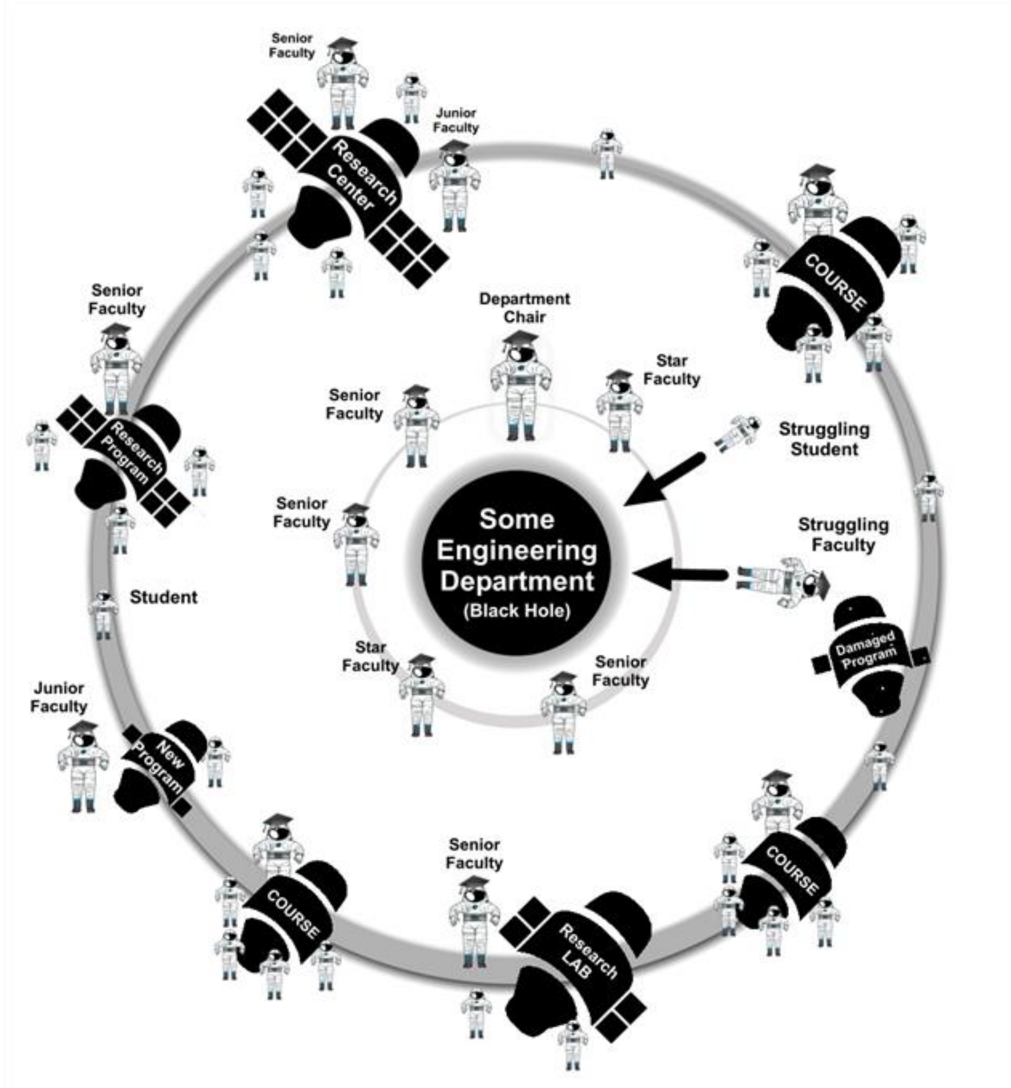

Figure 3.2: *An example of the elements orbiting an engineering department black hole. New and mature research programs, courses, federally funded research centers, faculty, staff, students are all in orbit about the departmental black hole. The department chair, senior and star faculty orbit closest to the black hole as they have developed the momentum required to be near focal point of the department. Damaged programs, struggling students and faculty are threatened by this black hole.*

professor, or a technical professional) and they believe that the institution can provide the resources and training to be successful.

We propose that gravity in this context is the expectation to succeed. Specifically, it is the attractive force that results from the expectation that there will be success, recognition, advancement, or attainment of the desired outcome (e.g., graduation, funding, promotion.) The reputation of a department or institution warps the academic fabric and attracts talent who is seeks success at that institution. It is the expectation of success that causes the participant to endure the gravitation forces of the institution. Navigating this orbit under academic gravity requires guidance.

3.2 Institutional/Departmental Black Holes

Metaphorically, black holes in this context represent a structure within an academic department that is without light or guidance. Students and faculty in orbit around this black hole are observable. However, their drift towards the departmental black hole can be imperceptible. Figure 3.3 shows how an isolated student and struggling faculty member fall toward the department black hole. The area within the entire black hole is very dark, but on the periphery, the student's trajectory can still be corrected. The gray region is where the student can still correct their course before the point of no return. The struggling faculty member in Figure 3.3 has already crossed the Event Horizon and cannot be rescued. This person will experience a form of spaghettification, which will be discussed in Section 3.3.

Falling into an orbit leading to the center of a black hole is a needless outcome especially since the consequences are so great. The black hole may unnecessarily consume talented people when the understanding of the orbital mechanics (skills to handle opposing forces) are not conveyed or facilitated. Figure 3.3 also illustrates a junior faculty member who is led away from the increased gravitational forces of the black hole by a mentor. Our metaphorical black hole can be avoided by developing constructs that develop students' STEM identity such that the gravitational pull (the invisible force that causes massive objects to pull other objects towards them) is strong enough to withstand biases and gaps in mentoring. Graduate student professional development programs that infuse external mentors into students' environments can provide thrusts that avoid black holes.

3.3 STEM Spaghettification

Why model engineering departments as black holes and not planets? Failed orbits around planets simply end in a fiery thud. Failed orbits around black holes lead to spaghettification. Spaghettification, as mentioned in our earlier discussion on actual black holes, is process where the tidal forces of gravity stretch the falling object ultimately into a thread of atoms of the original object after it enters the Event Horizon.

No one knows for sure where these atoms end up however, some theories proposed these atoms may reappear in a different form in another (part of the) universe. The black hole more accurately models what happens when faculty or students from diverse backgrounds drift into decaying orbits in their departments.

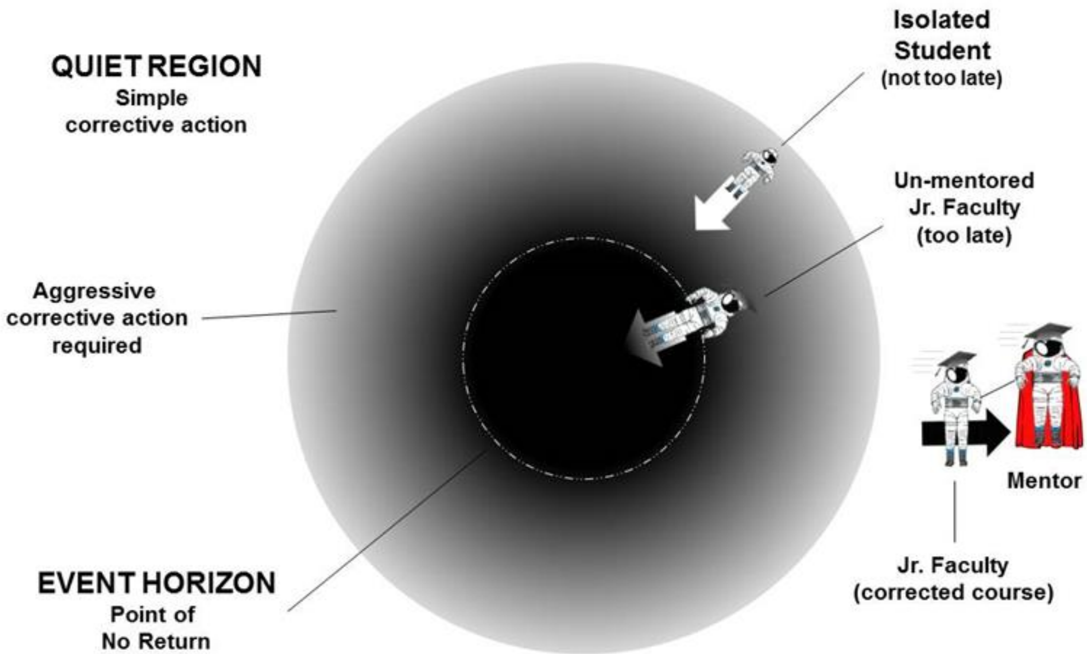

Figure 3.3: *An isolated student and un-mentored faculty are subject to the forces of their departmental black hole. In the gray region, the student can still be rescued. Unfortunately, the un-mentored faculty member crossed the Event Horizon, the point of no return. Another junior faculty member received mentoring and was able to correct course.*

If this often unnoticeable drift is not corrected in time, they can be consumed by the black hole of their department. After spaghettification, they often reappear in other fields unrelated to engineering or STEM in general. Tragically, outside observers don't see the damage because events occurring inside of the event horizon are only evident inside the black hole.

It is strategically important to avoid ***'STEM spaghettification'*** effects in order to maximize the number of competent professionals in STEM fields.

4.0 Connecting Social Science Theories to Developing STEM community

The orbits surrounding STEM academic environments can have effects on diverse scholars that differ from those of their majority, i.e., designated non-minority, counter-parts. There are challenges related to broadening participation in engineering that can be considered "black holes" in the metaphorical space-time continuum that constitutes the "ivory tower." Experiences of underrepresented scholars in engineering (undergraduates, graduate students, faculty) have been wrought with problems that have affected recruitment, retention, degree completion, and transition to careers. In this section, we will briefly discuss the three social science theories that can be used to develop an overarching construct for developing STEM community: 1) Psychological Sense of Community, 2) Counter Spaces and Cultural Capital, and 3) STEM Identity.

4.1 Sense of Community

The theory of Psychological Sense of Community has been called the "basis of self-definition" and is most simply described as "a feeling that members have of belonging, a feeling that members matter to one another and to the group, and a shared faith that members' needs will be met through their commitment to be together."[12, 16] McMillan & Chavis (1986) further describe four elements of a sense of community in terms of membership, influence, integration and fulfilment of needs, and shared emotional connection. Within these elements lie concepts such as the importance of personal contact, acknowledgement of values, and emotional security. When thinking about where and how to incorporate these elements into a physical dimension, the need for space, e.g., a place, comes into question. Thus, the second theory of having alternate spaces can be introduced to our overarching STEM community construct.

4.2 Counter Spaces and Cultural Capital

A community needs a space with which to operate, and a STEM community's needs are no different. Academic spaces are not always welcoming to students of color. Using "counter spaces" explores the concept of having different spaces, other than those within academic classrooms that provide an environment that facilitates success. The "third space," a term coined by Ray Oldenburg is "a setting beyond home or work, in which people relax in good company and do so on a regular basis." It's a place that is welcoming, safe and familiar. The term that we will use from the literature is "Counter-spaces." Counter spaces, also called "alternative spaces" are conceptually associated with Critical Race Theory (CRT), and the idea spans across multiple disciplines.[19] The description used in this paper will be based on the framework that is used for education. Solorano, Ceja & Yosso state that, "The critical race theory framework for education is different from the other CRT frameworks because it simultaneously attempts to foreground race and racism in the research as well as challenge the traditional paradigms, methods, texts and separate discourse on race, gender, and class by showing how these social constructs intercept to impact communities of color." Conceptually, we are considering spaces where people of all backgrounds can thrive and succeed. According to Schwartz, counter spaces are considered an "other" and are "different from" traditional institutionalized racist school spaces.[17] Similarly, Solorzano, Ceja, & Yosso incorporate counterstories (another aspect of CRT) but are dimensionally larger. More often than not, counter spaces, which are created in race settings, affirm a marginalized group's life and racial experiences.

Counter spaces also allow opportunities for cultural capital to thrive. Cultural capital, can be best described as a "non-material resource" that accumulates throughout the life course.[11] Similarly, "Cultural capital is acquired through education and socialization and includes "the distinctive forms of knowledge and ability that students acquire [...] from their training in the cultural disciplines."[4] Cultural capital takes shape in three forms. Those forms include: incorporated, objectivized and institutionalized. Using Yosso's model for cultural wealth to acknowledge the strengths of communities of color, we note that cultural capital includes supporting one's aspirations (Aspirational), honoring language differences (Linguistic), valuing formal and informal family structures (Familial), appreciating and facilitating connections to peers and other communities (Social), maneuvering within institutional environments with faculty (Navigational), and appreciating needs to be involved with issues of social justice (Resistant). All of these forms of cultural capital can be acknowledged and supported within a counter space or a healthy academic orbit.

4.3 STEM Identity

The third social science construct is the notion of having a strong sense of identity regarding one's discipline. Carlone & Johnson's discussion on STEM Identity notes that people with strong STEM identities demonstrate competence in the discipline, possess the skills to perform scientific practices, and achieve recognition (from oneself and meaningful others).[5] STEM Identity encompasses three constructs that are interrelated: Competence, Performance and Recognition. In essence, a strong STEM Identity is shaped by the individual's own assertions and experiences in STEM, albeit positive or negative. In addition, a strong STEM Identity shapes trajectories within STEM disciplines. Their research with women who had research scientist identities showed that there was importance in needing to recognize oneself as a scientist, and to in turn receive recognition "by meaningful scientific others." The study goes on to note that bids for recognition were not always answered, and that they didn't always receive the recognition that they sought, hence, the STEM identity was disrupted.[5]

5.0 Experimental Methods

This section will look at three short investigations that examine ways that students can be kept in orbit. The experiments are based on structures that are used in the design of professional development seminars and workshops for graduate students that are underrepresented in STEM. Sections 5.1, 5.2, and 5.3 below will describe the methods for developing an orbit for retention, using mentoring and self-efficacy to facilitate solutions for successful matriculation, and avoiding "black holes" by using student feedback to fulfill needs. The investigations use a phenomenological approach as its qualitative research method to study "phenomena."

5.1 Part 1: Developing an Orbit for STEM Success

In one NSF-program, data showed that Black and Latino graduate students in engineering and IT programs experienced a sense of mentoring in external workshops that they didn't regularly receive within departments. Further, these seminars influenced students to strengthen their STEM identity. These kinds of interventions metaphorically return us to physics, as objects can avoid destructive black holes if they are thrust into orbits that are far enough away from the event horizon. The physics will be used to describe problems that occur within graduate student and faculty mentor relationships, with emphasis on experiences from underrepresented students. Physics metaphors coupled with social science research and graduate student data present an interdisciplinary approach to demonstrate that student motivation and success are possible with purposeful attention to the academic environment.

PROMISE, an Alliances for Graduate Education and the Professoriate (AGEP) program in Maryland, sponsored by The National Science Foundation, offers supplemental professional development seminars and workshops to graduate students from universities within the region during the academic year and semester breaks. These holistic and professional development workshops are primarily marketed to graduate students who are underrepresented in STEM fields, e.g., African-American, Hispanic/Latino, American Indian/Alaska Native, Native Hawaiian/Pacific Islander. The PROMISE AGEP for the 12 institutions within the University System of Maryland has held a growing number of professional development seminars for graduate students since 2003, and held 43 seminars for graduate students and postdoctoral researchers during 2014-2015. Many of these seminars are held in locations that are outside of the classroom, either in a campus common area such as a room in the Student Center, or off-campus, thus fitting the definition of a third space. This paper will discuss the PROMISE AGEP's Summer Success Institute, the largest of the annual events. The Summer Success Institute (SSI) has been designed for graduate student success and is purposely held in a local hotel. The SSI includes graduate students and postdoctoral researchers from a variety of campuses in the state, and features keynote guest speakers who are diverse faculty from underrepresented ethnic backgrounds. These guest speakers are in STEM disciplines, with a large number from colleges of engineering in the U.S.

The Summer Success Institute (SSI) sponsored by Maryland's PROMISE AGEP is designed to be an external weekend-based orientation to graduate school for students of color in STEM master's and doctoral programs. The SSI is held at a hotel or conference center. Students have an opportunity to learn about the program through several platforms, and during the registration process, they are asked how they learned about the program: PROMISE AGEP website, Facebook page, Twitter, Faculty member, University staff member, friend or colleague, the AGEP's listserv, the AGEP's electronic digest, or general email. When students and alumni register for the SSI, they are asked a series of questions related to demographics, and expectations. Among them are the following questions related to motivation and perceived effects. Table 5.1 demonstrates a subset of the questions that were presented to the participants during the online registration process. The questions were designed to present potential participants with opportunities to consider reasons for their participation, and to alert them of the kinds of experiences that they should expect. These registration questions supplemented the event's website, which also had information regarding the conference. The answers to the questions allowed the conference organizers to focus efforts on particular sessions, and to invite engineering faculty of color from across the country who would be able to meet the expectations.

Table 5.1: *Questions from the pre-registration process for the Maryland PROMISE AGEP Summer Success Institute, and the options that were presented in the menu.*

Questions	Options for Answers, Presented in a Pull-Down Menu.
If you have attended the SSI in the past, what is motivating your return?	Networking with peers | Networking with faculty and professional speakers | Motivation for the upcoming year | New information that can be used for professional development
What have you gained from the SSI that you wouldn't have gained otherwise?	Motivation to consider becoming a professor | Access to an internship or job | New tips for public speaking | Skills for social media interaction in research | Overcoming the impostor syndrome | Resilience: encouragement to continue to reach for academic goals
What have you used from SSIs in the past that have had a positive effect on your graduate school or professional career?	Guaranteed 4.0 information (book or session) | Information for obtaining a faculty position | Information about different kinds of careers | Motivation from AGEP alumni | Motivation from other AGEP students | Motivation from faculty and speakers
What do you expect to receive from the SSI?	Positive interactions with peers | Opportunities to network with professionals | Internship or job | Motivation to persist to finish the degree | Information for how to move to the next level in my career | Information on work/life balance | Advice for how to have a successful academic year

For the 2013-2015 range, there were three SSI programs, with a total of 576 registrants. Each SSI in 2013, 2014, and 2015 asked the same pre-registration questions, four of which are included above and are designed to set the expectations of the participants. The SSI programs include sessions that address academic orientation to graduate school, advancement, and social consciousness. Within the three year period, there were more than 30 sessions, including keynotes, panels, breakouts, and small group roundtables. A subset of these session titles are listed in Table 5.2 to demonstrate the type of content that was presented during these SSI conferences.

Table 5.2: *2013, 2014, and 2015 sessions from the PROMISE Summer Success Institute orientation, connection, and advancement programs for STEM graduate students, postdocs, and alumni of color.*

The Importance of Broadening Participation to National Defense
Mentoring for Career Growth & Transition (How to continually be a good mentee and how to develop the 'Career Mentor' relationship.")
When Bricks and Sticks are Replaced by Clicks: MOOCs – The Next Wave"
Making the transitions (grad student to PhD, postdoc, professor), keeping your cool, and addressing the issues:

How do you deal with the lack of respect on the new job that may come from subtle discrimination based on age, gender, or race?
Leveraging Your Faculty Position to Start a Viable Business
Making international connections and leveraging your faculty position for research opportunities
We Fall Down, But We Get Up: Resilience for the Journey
Book Discussion & Dessert Session: Sisters in the Dissertation House
Panel: Breaking Resistance to Networking, Mentoring Models, and Systems of Thinking

Following the seminars, participants are presented with an exit survey that assesses responses using a 5-point Likert scale, including opportunities for qualitative feedback.

5.2 Part 2: Toward Invoking Cultural Capital: An Environment to Discuss Isolation

The sessions in Table 5.2, and those throughout the years of the SSI's existence (2003-present), along with students' responses to SSI sessions in the past helped to shape the evaluation process for the 2015 SSI. The 2015 SSI used a hacking-styled approach to engage students and allow them to work with visiting faculty and professionals from underrepresented ethnic groups who served as "Mentor-coaches." There were three groups: New/incoming students, continuing students, and the PP&P (Professors, postdocs, professionals). New/incoming graduate students were designated as Group 1 for the SSI, and all participants in Group 1 were presented with a list of five "Challenge Areas" under the umbrella title: "Mitigating Risks in the First Year- Eyes on the Prize." The Group 1 Challenge Areas included 1) Time management, 2) Understanding professors' expectations, 3) Differences between undergraduate and graduate coursework, 4) Isolation, and 5) Expectations from family and obligations to the community. For the purpose of this paper, Challenge Area #4, Isolation, will be discussed.

The first-year (incoming/new) graduate students were give the following challenge related to isolation:

> *Graduate students often work alone due to shyness, discomfort with a group, or lack of invitation to join a group. Some students choose to work alone in an attempt to prove worthiness, without realizing that those around them regularly collaborate and share knowledge.*

Students were asked to work with the Mentor-coaches to discuss and record their questions related to isolation, and potential solutions toward mitigating the risk of isolation. There were 188 SSI registrants for 2015; 52 of whom were first year students. The new/incoming student participants in Group 1, along with their Mentor-coaches, generated 66 solution/strategies for the five Challenge Areas. Twenty of the 66 responses directly addressed Group 1's Challenge Area #4: Isolation.

5.3 Part 3: Fostering a Sense of Community - Avoiding Black Holes
During the Fall semester, the multi-campus PROMISE AGEP program holds an annual dinner, the week before the Thanksgiving holiday. Graduate students from all of the campuses within the AGEP alliance are invited to attend. Announcements are shared through social media, email, listservs, faculty, and university staff members. Students are invited to sit at tables that connect them by discipline. The program includes a short welcome address, a buffet dinner, and a short motivational speeches by five graduate students and postdoctoral fellows. During the pre-registration process, students are asked to answer the following questions using an online entry system:

1. If you've come to Fall Harvest in the past, what was the most significant thing that you gained from the experience?
2. Do you believe that the Fall Harvest Dinner will provide a sense of community?
3. Do you believe that a sense of community provides motivation for completing degree or career goals?

There were 127 registered responses to these questions. Responses were categorized by theme.

6.0 Results

With the implementation of programs such as the SSI and the Fall Dinner, the PROMISE AGEP has been able to gather some important data. *5.1 -Part 1: Developing an Orbit for Success*, demonstrates that students are provided with information that informs them of the intent of the particular AGEP workshop. Students' ability to choose options from the pull-down menu confirms the participants' intent to receive an expected outcome. The students came to the SSI expecting to receive the outcomes that were presented during the pre-registration process. Expectations that were expressed using the pull-down menu such as "Opportunities to network with professionals," and "Information for how to move to the next level in my career," were realized. As an example, data from the 2012 SSI show that of those who completed the exit survey (n=42), 98% "mostly" or "completely" agreed that the SSI Career Session "gave me useful information about future career options and plans," and 96% mostly or completely agreed that "This session gave me new ideas about networking," and 91% mostly or completely agreed that "This session helped me feel more confident about my professional future." The data from seminars show that PROMISE is reaching its intended audience of diverse STEM graduate students, and is relaying important information that students who otherwise felt that they would not have access to if they had not participated in some of the seminars and workshops.

In the second of the three investigations discussed here, *5.2 -Part 2: Toward Invoking Cultural Capital: An Environment to Discuss Isolation* looks at one of three groups of participants who addressed "Challenge Areas" related to retention and advancement during the 2015 SSI. Group

1, the new/incoming students, generated 20 responses related to their “Mitigating Risks” Challenge 4: Isolation. The responses revealed that the students acknowledged that they were new, and that making new connections was a challenge within itself. These students openly acknowledged that they were in the process of learning how to connect to new people. There were concerns about overcoming shyness, and students wanted to have opportunities where they could participate in networking events, and reduce passivity. The peer-to-peer advice for addressing isolation included the following themed responses:

- **Connect with a group.** “Join your school's diversity group, e.g., [the National Society of Black Engineers] NSBE or [the Society for Hispanic Professional Engineers] SHPE to meet more diverse students,” “Make time for social interactions.”
- **Participate in events - face to face.** “Stop hiding behind technology and engage in face to face,” “Participate in networking events.”
- **Actively engage.** “Speak up more,” **“**Give yourself an attainable goal for the event, e.g., Get [business] cards for 2 people; grow your goals.” “Start with a simple greeting and write down open questions (avoid yes or no questions)”
- **Encouragement - “You are not alone.”** Know that you are not the only one feeling isolated,” “You don’t need to completely isolate yourself,” “Stay motivated and engage with your group when working in teams.**”**

The third investigation examines responses to pre-registration questions that are given to students who will be attending a Fall multi-campus dinner. This 2015 event took place 3 months after the 2015 SSI program described in Part 2 above. Section *5.3 -Part 3: Fostering a Sense of Community - Avoiding Black Holes* explores open-ended responses to the question, “If you've come to Fall Harvest in the past, what was the most significant thing that you gained from the experience?” Themed responses were as follows:

- **Networking and connections.** “Connecting professionally and socially with similar scholars, being introduced to new connections,” “Connecting with other graduate students,” “I hope to network with other students, and learn about their research topics.”
- **Sense of Community.** “A sense of community. Attending Fall Harvest has been a motivating experience for me,” “A sense of community and motivation to keep working,” “You can feel the sense of community and a very strong network support,” “This event provides continuity for alumni to keep in touch,” “Reconnecting with friends,” “Community and extended family,” “Having a community to share the experience and journey with, and possibly future colleagues to be a source of help to and who will be sources of help to me,” “Connecting with fellow STEM colleagues who share the common bond of being a minority - having the sense of community to provide a support system but also to provide cross-functional bonds and aids with research is also a desired benefit,” “Developing community with Latino students.”

- **Motivation.** "Motivational, inspirational talks," "It was very inspirational to me to hear from the students who had just defended or approaching their defense. Their stories were very motivational and relatable," "Inspiration from speakers' experience," "Hearing about other students' struggles and how they overcame them."

The following questions were also asked during the pre-registration survey: "Do you believe that the Fall Harvest Dinner will provide a sense of community?" and "Do you believe that a sense of community provides motivation for completing degree or career goals?" All of the registrants responded "yes" to each question, 100%, N=127.

7.0 Discussion: Connecting Social Science to Physics Metaphors

Linking observed phenomena in educational settings and phenomena from physics is a difficult endeavor, and one that can be quite subjective. While some of the connections were explained in the section on "Academic Orbits" above, this section will provide some additional linkages to demonstrate the perspective that is being portrayed in this paper. Table 7.1 summarizes the metaphors that are being used here.

What are the factors or forces that remove people from the realm of STEM? What is the point of no return? This "leak in the pipeline" occurs throughout the pathway, affecting diverse longevity in engineering at every level K-12, undergraduates, graduate students, postdoctoral fellows, and faculty. There are forces that can assist with the maintenance of a positive orbit. For example, inviting diverse scholars to collaborate on research projects, providing freedom for and acceptance of diverse research pursuits, and of course providing levels of mentoring and guidance throughout the career. Some of the forces that assist with maintaining an orbit are summarized in Figure 7.1.

Table 7.1: *Physics and Social Science Metaphors*

Physics	Social Science & Education
Galaxies	The institution, colleges
Orbits	The velocity and path required to attain academic progression or advancement goals without succumbing to the central force of gravity (e.g., the dynamics of the engineering department.)
Gravitational Pull	The force that results from the expectation that there will be success, recognition, advancement, or attainment of the desired outcome (e.g., graduation, funding, promotion.)
Black Holes	Structures within an academic department that are without light or guidance. These are unnecessary pathways for easy departure, "weed-out" or attrition. • The structure itself may unnecessarily consume talent

	when the understanding of the orbital mechanics (skills to handle opposing forces) are not conveyed or facilitated.
Event Horizon	The boundary, once crossed, that leads to a departure from the STEM environment (e.g., the department, the field.) This is literally, the point of no return.
Spaghettification	STEM Spaghettification: The process where a scholar falls into a black hole, leaves STEM, and later reappears in another academic field.
Dark Matter	Invisible structures that hold a department or college together, and can facilitate community, identity, and opportunity. In the academic orbit, these invisible structures include recognition of one's humanity (greetings, cordial behavior), assistance, consensus or amicable disagreement (as opposed to passive-aggressive resistance), trust, appreciation of differences, etc.
Drag	Any force that impedes the progress or development of a scholar (in orbit).

7.1 Circumnavigating the Academic Black Holes

In order to circumnavigate, avoid, or bypass the black holes, one must acknowledge their existence. Ignoring the fact that black holes exist, leads back to ignoring the event horizon and the issues that create a gravitational pull to a "point of no return." Here are some questions that we sought to address:

Forces That Maintain Orbit	Forces that Distort / Degrade Orbits
Classwork • Research • Collaboration • Mentoring • Experiences (Co-ops/Internships) • Micro-Affirmations • Advising Professional Development • Interventions • Support Resources • Healthy Competition	Lack of academic support Lack of mentoring Micro-aggressions Isolation

Figure 7.1: *Forces that Affect Academic Orbits and Gravitational Pull*

1. What is it that takes someone out of the realm of STEM, moving them to a point where they will leave their STEM discipline and not return?
2. Do students know about their respective orbits and do they understand them?
3. Is there recognition of the forces that keep people in orbit, beyond the force of "academic excellence?"

The AGEP program and programs that provide support systems for students can fulfill a critical role in supporting the recruitment, retention, and growth of underrepresented students in engineering. Programmatic components of these interventions and initiatives such as developing a sense of community, supplementing academic supports that are not offered by the academic department, and providing professional development opportunities clearly address key areas of the retention theories put forth by Vincent Tinto, Raymond V. Padilla, and Douglas A. Guiffrida, John Bean & Shevawn Eaton.[7, 14, 21]

These concepts were applied to global diversity in engineering in 2014 after noting that there were retention theories that could be applied to developing programmatic actions and to inform policy for the issues surrounding engineering attrition.[1] Vincent Tinto's theory of individual departure assumes that students leave college as a result of the individual student attributes, skills, commitment, intentions, and interaction with members of the college. Tinto contends that the more a student can integrate into a college environment, the more likely the student will be to persist and finish his or her degree. Tinto describes this integration in a three step process: 1) separation from the past community, 2) transition between communities, and 3) incorporation into the community of the college. The premise is that students must assume the culture of the college environment in order to successfully obtain a degree. In 1997, Padilla's research sought to determine the heuristic (trial and error, experimental methods) strategies of successful college students. A study was designed with the objective of using the expertise model of successful college students to develop a local model of successful ethnic minority students at a large research university in the Southwest. In this model, there were four categories of barriers: **Discontinuity** – Obstacles that hinder the transition from high school to college; **Nurturing** – No nurturing presence on campus; **Presence** – Limited availability of culturally grounded activities; and limitations in **Resources**– e.g. Financial Aid. All of these are forces that affect orbits.

Programs like the PROMISE AGEP have addressed some of these barriers, thus keeping students in an orbit with a force that prevents gravitation toward a black hole. As an example, programs such as the summer bridge programs for graduate students and dissertation bootcamps (Virginia Tech, Cornell, UMBC) can be seen as tackling Padilla's identified barriers of discontinuity, nurturing, presence, and resources because the programs address obstacles of transition through seminars/workshops, they develop nurturing spaces on and off campus, they include culturally grounded resources such as Mentors-In-Residence and Career-Life-Balance assistance, and resources are available to cover participants' conference expenses.

Guiffrida's model looks at Self Determination Theory, noting that students are motivated to learn through either intrinsic or extrinsic motivating factors, and that more meaningful learning occurs when it is intrinsically motivated.[7] Guiffrida's work speaks directly to the work here regarding the importance of cultural capital, critiquing the missing cultural component of Tinto's theory of student departure. Guiffrida notes that minority college students need to "retain and nurture their connections to their cultural heritage." Expanding on Tinto's theory, Guiffrida noted that cutting oneself away from the community of origin may not be appropriate for all students and posits that the term *integration* be replaced with *connection* to describe the role that the home social system can play in supporting minority students in a higher education setting.

The Tinto, Padilla, and Guiffrida models for explaining student departure, barriers to successful transition, and needs for connection, can be combined with the action of developing orbits that include McMillan & Chavis' elements for sense of community, Yosso's aspects of cultural capital, and Carlone & Johnson's components for STEM Identity.[27] All of these models can be used to develop supportive environments that metaphorically reduce drag toward the black hole, and increase the gravitational pull toward an orbit that will yield success.

8.0 Recommendations and Conclusion

In the context of this discussion, dark matter is good. Dark matter and its associated energy represents 96% of the universe. In contrast, the observable energy only represents 6% of the universe - representing what we see. Dark matter represents the intangible thing, the unobservable things - unseen forces that are keeping things in orbit and holding it together. As an example, if a department doesn't invite a worthy and academically accomplished candidate of color to proceed in a faculty hiring process on the basis of "lack of fit," where the expressed "lack of fit" is cultural, it's possible that the department is only paying attention to their "observable universe," or those things that they see. The department has not yet taken an opportunity to appreciate the existence of the "dark matter" such as a person's cultural customs which can evolve methodologies and paradigms, or racial and class differences that can challenge current scientific perspectives and influence advances in research. Results from the investigations described in sections 5.1, 5.2, and 5.3, with the graduate students who have participated in initiatives sponsored by the PROMISE AGEP program show three things:

- *It's possible to develop an orbit for success:* Setting expectations and then developing pathways to meet them should be part of a program that supports the academic and professional advancement of underrepresented students in STEM. Paying attention to aspects of cultural wealth such as aspirational capital and use of third spaces can facilitate program development.
- *Invoking cultural capital and a sense of community should be intentional.* Students who participated in the AGEP's external professional development programs are receiving information that they are not necessarily receiving within the academic department. The AGEP's programming provided additional forces such as mentoring, advising, and a support resource that have the potential to maintain an orbit.
- *Maintaining a sense of community and combining it with STEM identity can prevent the drag toward the black hole.* Programs can be designed to incorporate one or more of the social science constructs that have been used by the AGEP. Use of these methods can provide students with a sense of community that has expectations of positive outcomes.

> The expectation of success is part of the gravitational pull that prevents scholars from falling into the metaphorical black hole.

The PROMISE AGEP's Fall Harvest Dinner was an example of connecting all of the social constructs that have been discussed in this paper. The dinner was held in a third space, and it created a space that celebrated STEM Identity. Postdocs, and faculty administrators who are part of the AGEP also attend the dinner, and these "important others" validate the STEM Identity of the students along with their own peer-to-peer STEM ID recognition. The sense of community is strong because the dinner and provided a sense of community. It is an annual event that includes each of the 4 elements of the Psychological Sense of Community: membership, influence, integration and fulfilment of needs, and shared emotional connection. Further, the Fall dinner from section 5.3 includes cultural capital. Linguistic capital is invoked because languages are celebrated (primarily Spanish and English), and familial capital is included because students are encouraged to invite family members, friends, and significant others. Aspirational capital is included because there are motivational speeches by advanced graduate students and postdoctoral scholars. Social, navigational, and resistant capital are involved because the deans and staff who are present validate students' thoughts about various social justice issues (e.g., #BlackLivesMatter), and there are discussions regarding ways to be expressive and participate in political processes while navigating the STEM doctoral degree process.

In the case of graduate students, the following actions can increase retention of underrepresented STEM scholars and reduce the liklihood of the trajectory toward the black holes:

1. **Have someone in the department who is responsible for student tracking.** Students should not be allowed to move through a program without sufficient oversight, particularly as time for addressing milestones for progression approaches.
2. **Implement a biannual review between faculty and students, and provide opportunities for shifts in trajectories.** It is important for faculty to be aware of student performance, and for the student to understand faculty perceptions of their performance, and faculty expectations for future work. Outcomes such as grades or progression, should not be any surprises on the part of the faculty member nor the student.
3. **Openly encourage underrepresented students to participate in organizations that build both academic and cultural capital.** Graduate students often fear the perceptions of their dissertation advisor. Students may not participate in programs such as AGEP, NSBE, or SHPE, because they are concerned about the disapproval of their faculty for participating in an organization that has cultural connotations, even when it is within STEM. Faculty can better support underrepresented graduate students by having an awareness of cultural engineering organizations and encouraging students' participation. This level of validation allows a level of navigational capital, and also assists with the students' STEM Identity.

4. **Build students' STEM Identity by publicly lauding their accomplishments.** This kind of action maintains the students' place in an orbit for success. Actions include a congratulatory note on the lab's website for a publication or conference presentation, acknowledgement of an accomplishment in lab group meetings, and sharing the accomplishment with peers during faculty meetings.

These metaphors were developed to assist departments with finding ways to avoid STEM spaghettification, the process where an engineering student would fall into a black hole, and leave STEM. Students who have already fallen through the metaphorical black hole, and have been "spaghettified" can be found in a variety of other sectors that are meaningful (e.g., business, health and wellness) but that are outside of the STEM enterprise. In an era where faculty diversity in engineering is becoming a more prominent issue, it is important to be sure that underrepresented students who make the choice to leave engineering do so as a result of making a voluntary and agreed upon choice to change orbits. With awareness of ways to develop orbits of support along with attention to the ever-present (but often-ignored dark matter), departments of engineering and other STEM fields can take steps toward mitigating destructive trajectories toward black holes.

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