Equitable and Inclusive Public Outreach with the James Webb Space Telescope: Combining Art, Science, and Technology

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NASA's James Webb Space Telescope revealed its first images on July 12, 2022 and has been doing groundbreaking science since. Communication is essential for involving the public in NASA's discoveries of our universe. Scientific exploration transcends international borders; it united humanity to make a mission like Webb feasible with collaborators including the European Space Agency (ESA) and the Canadian Space Agency (CSA). Art is a medium that can transcend the boundaries of language, culture, and ability. It can serve as a bridge for communication between the technical and non-technical communities to express the beauty and nuance of science and engineering, in ways that may not be readily perceived to those outside of those communities of practice. Equitable and inclusive outreach endeavors are challenging to implement while considering language translations, culture context, sensory methods, and technology capabilities. Formats including the "Unfolding the Universe" virtual reality platform have allowed a wider audience to interact with the Webb images including sounds, visual aids, and talks by the scientists and engineers who worked on Webb. This VR platform has been expanded to highlight the ESA contributors to the mission and will be showcased internationally. The Webb first images were also translated into sounds as a method of inclusion for the blind and low vision community. We will explore some successful outreach methods and suggestions for inclusivity in future.

Nomenclature

3D = Three-dimensional
ASL = American Sign Language
CSA = Canadian Space Agency
CXC = Chandra X-ray Center
ESA = European Space Agency
GSFC = Goddard Space Flight Center
HH = Herbig-Haro

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JWST = James Webb Space Telescope
LLC = Limited Liability Company
NASA = National Aeronautics and Space Agency
NGC = New General Catalog of Nebulae and Clusters of Stars
ONX = Onassis ONX Studio, an art studio in New York City
STEAM = Science, Technology, Engineering, Art, and Mathematics
STEM = Science, Technology, Engineering, and Mathematics
STScI = Space Telescope Science Institute
UCLA = University of California Los Angeles
US = United States
VR = Virtual Reality

I. Introduction to Equitable and Inclusive Public Outreach

Outreach and communication is essential to communicate the incredible science and engineering being performed at NASA. There are many avenues to disseminate discoveries to an international community with accessibility and inclusivity in mind. This paper explores various outreach methods that have been utilized to reach larger audiences and using art as a medium for science communication to transcend boundaries and improve inclusion and equity.

II. Introduction to the James Webb Space Telescope and Scientific Highlights

The James Webb Space Telescope is a large infrared space telescope with a giant gold-coated, segmented mirror and a tennis court-sized sunshield. Launched on December 25, 2021, it deployed in space on the way to its final destination in orbit around the Sun, at what is known as the second Lagrange point. Webb is "non-traditional" in appearance, given that it doesn't have a classic telescope tube surrounding its optics. The large exposed mirror is gold-coated to optimize it for reflecting infrared light, but it is also unusually beautiful - even from a non-technical perspective.

After a six-month commissioning process, Webb's first full color images and data were revealed to the public on July 12, 2022. Webb's science goals include solving mysteries within our own solar system, looking beyond it to distant worlds around other stars, and probing the mysterious structures and origins of our universe and our place in it.

Science highlights so far have included observations of: the Rho Ophiuchi cloud complex[1], the closest star-forming region to Earth; Cassiopeia A[2], the newest known remnant of a massive star exploding at the end of its life cycle; galaxies that existed[3] when the Universe was only hundreds of millions of years old; some of the earliest black holes[4] in the known universe; energetic jets[5] bursting from young stars producing shockwaves as they collide with gas; Jupiter[6], Saturn[7], Uranus[8], and Neptune[9], including their rings; galactic mergers like Arp 220[10], the brightest one we can see from Earth; exoplanet atmospheres, including several of the planets in the famous TRAPPIST-1[11] [12] system; as well as confirming the Hubble tension[13], the mysterious difference in values of the Hubble constant when it is derived by different methods. Figures 1 through 5 below feature some of the stunning visuals from Webb since the release of its first images.

Figure 1 (left). Sun-like stars are being born in this detailed close-up of Rho Ophiuchi, the closest-star-forming region to Earth. Credit: NASA, ESA, CSA, STScI, Klaus Pontoppidan (STScI), Image Processing: Alyssa Pagan (STScI)

Figure 2 (right).Herbig-Haro (HH) 797. A Herbig-Haro object is the bright region that surrounds newborn stars, formed when the stars' outflows collide with nearby gas and dust at high speeds. Credit: ESA/Webb, NASA & CSA, T. Ray (Dublin Institute for Advanced Studies)

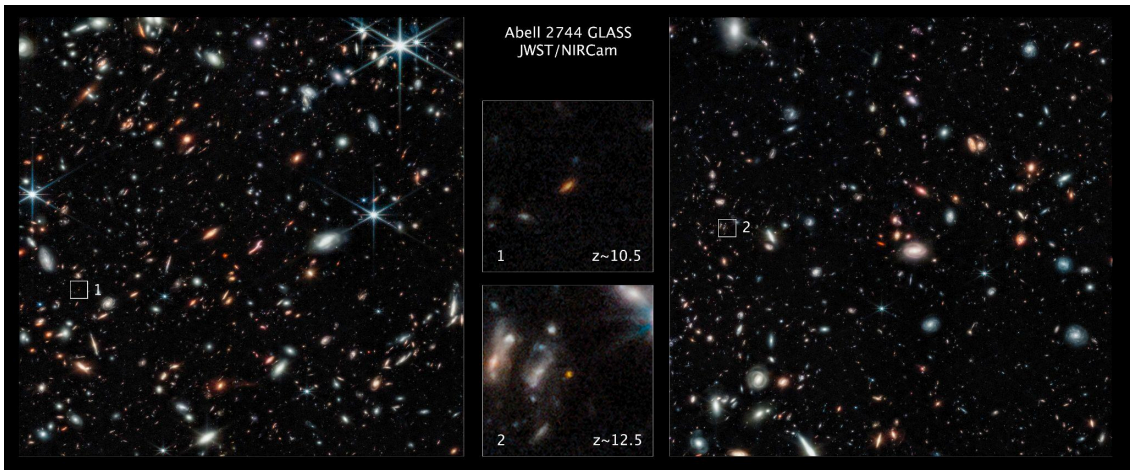

Figure 3. Two of the farthest galaxies seen to date are captured in these Webb Space Telescope pictures of the outer regions of the giant galaxy cluster Abell 2744. The galaxies are not inside the cluster, but many billions of light-years farther behind it. The galaxy labeled (1) existed only 450 million years after the Big Bang. The galaxy labeled (2) existed 350 million years after the big bang. Both are seen really close in time to the big bang which occurred 13.8 billion years ago. Credit: Science: NASA, ESA, CSA, Tommaso Treu (UCLA); Image Processing: Zolt G. Levay (STScI)

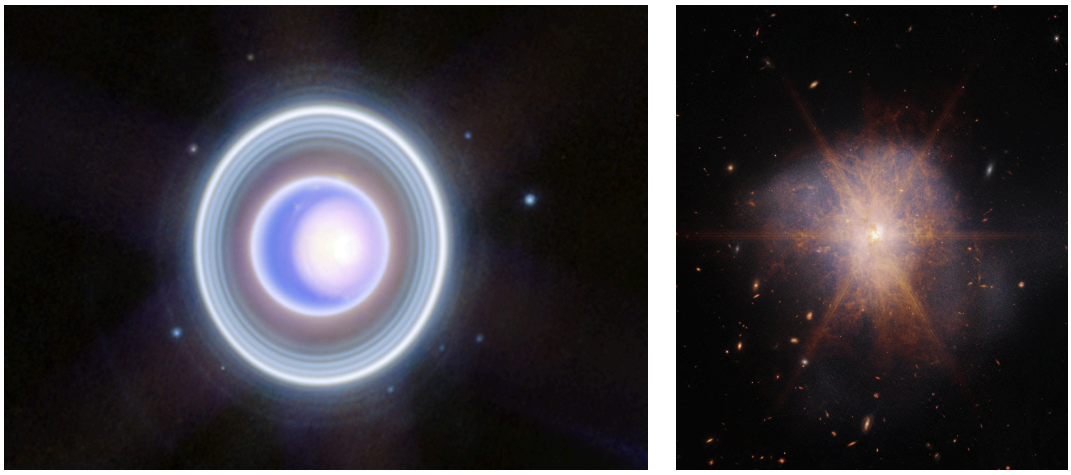

Figure 4. (left): New Webb images of Uranus reveal detailed features of Uranus's seasonal north polar cap, as well as bright storms near and below the southern border of the cap. Webb's sensitivity has even captured the close-in Zeta ring, faint, diffuse, and elusive. Credit: NASA, ESA, CSA, STScI

Figure 5. (right). A stunning smash-up of two spiral galaxies shines in infrared with the light of more than a trillion suns. Collectively called Arp 220, the colliding galaxies ignited a tremendous burst of star birth. Each of the

combining galactic cores is encircled by a rotating, star-forming ring blasting out the glaring light that Webb captured in infrared. This brilliant light creates a prominent, spiked, starburst feature. Credit: NASA, ESA, CSA, STScI, Alyssa Pagan (STScI)

With a new abundance of images and data produced by Webb, science communication focuses on sharing the wonders of Webb's discoveries in an engaging and informative way, while ensuring inclusion and accessibility. The following two sections detail successful communications efforts by Ashley Zelinskie (co-author), Conceptual Artist at Ashley Zelinskie Studios LLC and Director of The Active Space studios, and Maggie Masetti (co-author), NASA Social Media Lead and Web Site Manager for the James Webb Space Telescope mission. This section also references other parallel efforts, such as those by Apurva Varia, NASA Mission Director, and Dr. Kimberly Arcand, Visualization Scientist at the Harvard Smithsonian Center for Astrophysics, to ensure the greatest possible audience for Webb's findings.

III. Communications Methods for International Collaboration

Webb is an international project with the Canadian Space Agency (CSA) and the European Space Agency (ESA) partnering with NASA. ESA's working languages are French and English and it has 22 Member States: Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland and the United Kingdom. Latvia, Lithuania and Slovenia are Associate Members. Canada's official languages are French and English. Webb team members need to communicate with each other across culture and language, and the outreach and social media teams have the additional consideration of the languages and cultures of the members of the public who consume their content.

The Webb team created eight facts about Webb which Masetti then crowdsourced translations for, in over 40 languages[14], tapping into project members, friends, and personal and NASA social networks. For launch, Masetti sourced people to speak (or sign) a subset of the facts as well to wish the telescope good luck. Several videos using these recordings were created[15] and incorporated into launch promotion as well as the launch broadcast itself.

This process had both unexpected challenges and successes. Regarding challenges, Masetti received complaints when a language was missing, but it wasn't always possible to source translations in a particular language. It was difficult for Masetti's team to vet translations (other than using an online tool such as Google Translate) to ensure they were accurate, although these tools were used for proofreading to verify that there was nothing surprising included either facetiously or maliciously. There were differences of opinions in translation (there were several instances of people writing in to disagree with each others' translations) and indeed some words originally chosen did not translate well. In particular the word "tantalizing" (a descriptor of "discoveries"), proved extremely challenging due to its various contextual backgrounds in other languages. Lastly, there was no budget for paying translators, so Masetti relied on volunteers. These volunteers were generally happy to help but there was some negative feedback. One additional unforeseen problem concerned languages that read from right to left. These were difficult to work with on Adobe Premiere in closed or onscreen captions, and in Illustrator, finding fonts that would display correctly for the written language cards on the Webb website was a challenge. Conversely, one very successful aspect for this effort was the fun and creativity it encouraged as a way to engage the public. David Peterson, who created the Dothraki language for Game of Thrones, did a translation of Webb facts. Marc Okrand, who famously created Klingon, connected Masetti with the Klingon Language Institute and also consulted on a translation. As Webb is now past launch, Masetti is looking to officially update the facts to reflect the current status of Webb and will be incorporating the lessons learned from this one to another translation project.

Webb data has also inspired artistic virtual spaces and musical compositions to communicate Webb's findings across borders and languages. In 2022 Zelinskie created her first virtual reality artwork, "Unfolding the Universe: A NASA Webb VR Experience"[16] which includes interactive interviews with scientists and engineers from the James Webb Space Telescope team. Their interactive portraits line the perimeter of the virtual architecture. Digitally hand drawn by the artist and using sound mapping technology, the portraits can be triggered by the viewer's approach. Interviews between the artist and the scientist or engineer play upon approach to the interactive portrait. Zelinskie met with various members of the Webb Telescope team over zoom during the 2020 quarantine. Those recorded interviews covered everything from childhood dreams of science, special connections with telescope instruments, and hopeful scientific discoveries, to deeper, more abstract questions about the origins of the universe and our place in it. The work honors the extraordinary humans behind Webb and their decade-long stories of creating the

telescope. Viewers would be able to have an intimate moment with the Webb team members at any time, from anywhere in the world, with the click of a mouse. This type of artistic intervention is a bridge for technical and non-technical communities.

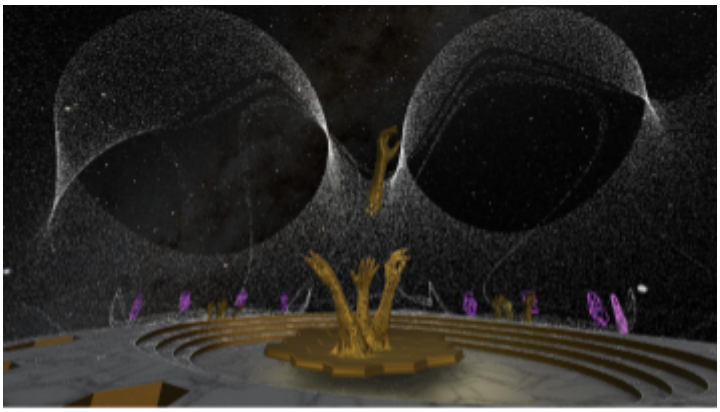

Figure 6. "Unfolding the Universe: A NASA Webb VR Experience"
(Image by by Ashley Zelinskie)

The VR space is also able to reach a large audience because of the choice of VR platform, Mozilla Hubs, which was chosen specifically because of its accessibility. The user solely needs an internet connection to participate. No VR headset is required, although it is formatted to work should they have one, and is extremely user friendly for both first time VR users and children. The virtual platform is also available via browser for multiple physical hardware platforms, including desktop, laptop, tablet, and smartphone. Upon entering the experience there are simple tutorials on how to control your avatar in the virtual space with a few clicks of a mouse or taps on a screen. This versatility made it ideal to host online lectures from the participating scientists and engineers, and timely for 2021 when COVID-19 lockdowns were still taking place. Participants were able to ask questions and interact live with Webb team members from their own homes. This VR experience continues to be an excellent avenue to reach people in far reaches of the world or those unable to easily travel due to constraints, including cost, or physical or mental health.

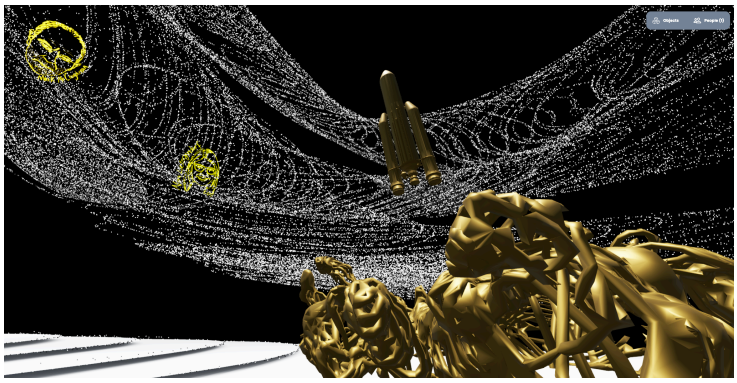

Figure 7. Updated 2024 version of "Unfolding the Universe" including ESA contributions (Image by by Ashley Zelinskie)

Zelinskie is currently working on expanding "Unfolding the Universe" to include the team and contributions of ESA. The centerpiece of this virtual world is an animated Ariane 5 rocket which ascends through the middle of a spiral stairway lined with portraits of ESA Webb scientists and engineers. The smoke cloud left by the rocket is made up of text and diagrams depicting the journey to L2. The clouds are shaped like the Pillars of Creation within the Eagle Nebula, foreshadowing one of the future images created by the device inside the payload. The artist's mission is to emphasize the international cooperation needed for a mission as ambitious and successful as Webb. She virtually met with fifteen members of the ESA Webb team from various countries in the European Union. International collaboration between NASA and ESA is highlighted in the piece as well as international collaborations between the many cultures, languages, and accents of the European scientists within ESA. This is also reflected in a question added to the interviews of the ESA Webb team: "why is international collaboration so important? and what have you learned from working with your international colleagues?" Their answers are extremely moving and are a testament to what we as humans can do when we embrace our differences and work cooperatively, a positive message in a divided world.

"Unfolding the Universe" is now being adapted for a 360° projection mapped dome. This will be an immersive experience where people can physically sit, stand, and walk around in the VR world. This is a great way to bring people together for a community-based version of the artwork: the audience will fly side by side through the virtual work and listen to the inspiring stories of Webb together. This version of the artwork will be debuted at the Texas Eclipse festival in April 2024 during the total solar eclipse passing over Austin Texas. The festival boasts 55,000 attendees per day over a 4 day event, 20 million people via social and digital media, and 2 million direct contacts via email.[17] They are a unique demographic of eclipse chasers, avid festival goers, and residents of the Austin and

Dallas area. There is an equal split between male and female attendees, as well as a wide range of household incomes, ages, and ethnicities. One of the more surprising metrics is the education divide: 40% of the audience will have no college education, which is largely different from an audience typically engaged with this facet of science. In presentations of this artwork both in the arts community and technical communities, the audience usually is college educated. Zelinskie sees this as a unique opportunity to engage with people who may be hearing about some of these concepts for the first time. The design challenge will be meeting them with artwork that they can engage with that is also educational at many different levels; this is something Zelinskie strives to incorporate in her work. Described as an art "onion" with many layers, the artworks hide several different levels of comprehension of the scientific material being described, with different layers appealing to those of different scientific background and education. The metrics provided by the producers of the festival are based on ticket sales and their past event for the Oregon Eclipse in 2023. This year's festival however includes a greater focus on space, science, and technology and includes talks and panels from people in the space industry including astronauts, scientists, and engineers from NASA as well as the private sector. Zelinskie has adapted the work as well as a few other artworks to fit the needs of this new, diverse audience.

Figure 8. The 360 video dome that will be at Texas Eclipse
(Image by by Ashley Zelinskie)

IV. Communications Methods for Accessibility

Masetti and Zelinskie have also explored effective methods for accessibility in science communication. In addition to the translations of Webb facts to different languages, Masetti also had the facts translated into American Sign Language by NASA Mission Director Apurva Varia. For the launch broadcast, Varia translated an introduction to the "Facts From Around the World" video. At Varia's suggestion, Masetti arranged for Justi Baldi, an ASL translator who had worked with Varia before, to do a voiceover for Varia's translation to ensure his words were properly translated. This suggestion emphasizes the need for consultation with accessibility experts, especially those who work with or are members of the communities that the science is trying to reach: this is not something that Masetti's team would have realized without external advice.

Allowing a core set of information to be made as widely available as possible is important for inclusivity. When Masetti first posted videos of the facts translated into ASL to Webb's social media, which were also promoted on NASA flagship accounts in platforms such as Snapchat and Instagram, the replies showed widespread appreciation. The following quotes provide a microcosm of the positive feedback received:

- [sic] "Today @NASA posted an Instagram story of a man using ASL to describe the James Webb telescope. I had not seen it used in such an instance, so put a smile on my face."
- [sic] "This makes my day. Love working for an agency that makes our exploration endeavors accessible to all."

The following feedback specifically reflects videos that were posted for Deaf Awareness Month in 2019, and the International Day of Sign Languages in 2020 and 2021. These videos also included extra Webb facts recorded at the same time:

- [sic] "I have so much respect for @NASA not only their work on understanding the universe but for their commitment to representing everyone, regardless of their background. Younger generations need to know that science is for everyone."
- [sic] "Oh thank u for the sign language for those all that can't hear the video!! There should be more videos out there like this for deaf people that don't want the sub titles in the way… I'm sure it means a lot to many many people as it did for myself…"
- "It is nice of you to include sign language in your video, this is the first time I've seen it in a space video."
- "Thank you NASA for shining a light on the Deaf community. We love you guys to the moon and back."

Zelinskie's "Unfolding the Universe: A NASA Webb VR Experience" incorporated a soundscape written by composer Ju-eh in 2022 specifically for the artwork. The track was created to play different elements depending on

where the user was in the space using 360 audio mapping technology. For the updated 2024 version of "Unfolding the Universe," Zelinskie is working with musicians Raquel Acevedo Klein and Asher Kurtz. This renowned duo is uniquely equipped for creating 360 audio that is also conceptually tied to scientific data.
A few of the pieces already created for the artwork include:

Figure 9. Able to See, scan to Listen *(Image by by Ashley Zelinskie)*

Able to See - Detuned piano, vocal melodies, and cassette tape loops resonate at 6 different frequencies derived from the visible light spectrum. The 6-part tonality represents JWST's ever-adjusting mirrors, which hexagonally shape our view of the universe. Frequencies (or pitches) pulsate through audio of Mark McCaughrean's (ESA Senior Advisor) speech, lensing the sound through an effects processor, affecting the way we hear other elements of the piece. The percussion transposes ultrasonic audio into the range of human hearing. This transposition parallels the process of False Color Imaging, where infrared light frequencies derived from Webb shift into the visible light spectrum. These processes reflect how we use machines as a lens to help us understand ourselves and our origins.

Figure 10. Approaching L2, scan to listen *(Image by by Ashley Zelinskie)*

Approaching L2 - A cosmic crescendo of shifting oscillators and reverberating electric guitar sonifies the rush of excitement that scientists felt as JWST unfolded and approached L2: the vantage point in space that enabled us to see further into our past than we had previously deemed possible.

Figure 11. Sunshield, scan to listen *(Image by by Ashley Zelinskie)*

Sunshield - Mechanical, sputtery robotic melodies accompanied by undulating layers of guitar expand outward to reflect on the importance of the multi-layered sunshield that constantly regulates the extreme temperatures JWST faces at its distance from the sun. This is required to keep the telescope's instruments performing in tip top shape.

Figure 12. 344 SPoF, scan to listen *(Image by by Ashley Zelinskie)*

344 Single points of Failure - Mangled notes in the low register of the guitarlele interlock with high frequency synth sirens to emulate the anxiety the JWST team felt after calculating that JWST could face 344 Single Points of Failure on the first leg of its mission. Any single point of failure would render the entire mission (including all of the money and politics that went into its development) inert. Pitched-down guitarlele provides jarring, accented gestures to evoke the magnitude and likelihood of the mission's collapse.

Light Shifts - Ascending pitch delays of a tape recorded guitarlele self-oscillating over a cosmic, synth generated radio static emulates the conditions of space and the distortions and light shifts we encounter while viewing deeper and deeper into the history of our universe. Redshifts or blueshifts are distortions in the light we observe from our place in the universe similar to the Doppler Effect with sound. Redshift occurs when things are moving away from us, and Blueshift when things are moving towards us.

Figure 13. Light Shifts, scan to listen
(Image by by Ashley Zelinskie)

Inspiration flows in multiple directions. Many of the sound pieces draw inspiration from Zelinskie's Webb artworks, and are designed specifically to complement the visual work. Conversely, the visual works—or components of them—are built specifically in response to the harmonies, melodies and soundscapes of the sound pieces. This iterative process between the artists builds on the shared foundation of Webb data, and results in a multi-sensory experience for observers.

Adjacent to the efforts for Webb, there is also excellent work being performed to support the blind and low vision community by experts at the Chandra X-ray Center (CXC) and System Sounds[18]. In 2020, they began the first ongoing, sustained program at NASA to create "sonifications" of telescope data. It is not coincidental that this project had its genesis in 2020; the pandemic isolated nearly everyone and disrupted ongoing projects, including one for creating 3D modeling and printing of astronomical data with members of the blind and low vision community. Making digital sound-scapes of data is something that could both be created and shared in isolation. It is also worth noting that accessibility includes allowing people that might be home-bound, whether through immuno-compromisation, caretaking duties, or other reasons to access information remotely. The pandemic highlighted the necessity of virtual access to information. The project is led by Dr. Kimberly Arcand, who is a Chandra Visualization Scientist, Dr. Matt Russo, an astrophysicist/musician, and Andrew Santaguida, a musician and sound engineer at System Sounds. Christine Malec, an accessibility expert, podcaster, and member of the blind community, has served as an ongoing consultant.

The sonification project started out using data from telescopes like Chandra (X-rays), Hubble (visible light), and Spitzer (infrared). When Webb joined those observatories in space in 2022, Webb data was also sonified[19]. The first three Webb sonifications created were Webb's image of the Cosmic Cliffs in the Carina Nebula, Webb's image of the Southern Ring Nebula, and Webb's spectrum of exoplanet WASP-96 b. There are more sonifications of Webb data, combined with multiwavelength data from other missions, actively being created. A documentary about NASA's sonifications, titled "Listen to the Universe," will be airing on the NASA+ streaming app in early 2024. These three new sonifications will be released in conjunction with the documentary.

While these translations of imagery into sound are a method of making something visible more broadly accessible, it is also an inherently artistic way of presenting astronomical data. Note that the sonifications are not actual sounds recorded in space, but rather are made by musicians and composers mapping the data to sound. The music represents the visual details of the image so that the features one might take in with the eye are instead able to be discerned by ear. Each one is different, and different techniques are used based on the object as well as the data available - also taking into consideration what makes sense for interpreting a specific piece of data, giving it meaning in an alternative medium.

Arcand did run a research study on sonifications[20] with blind and sighted users. The results showed high learning gains, enjoyment, an interest in learning more, as well as strong emotional responses. Blind and low-vision users showed slightly higher levels of engagement compared with sighted users. One surprising revelation is that sighted users came away with a better understanding about how others (e.g. the blind and low-vision users) might access data.

V. Exploration of Future Outreach and Communications Avenues

As discussed in the previous sections, the potential for art to be a medium for equitable access and inclusivity is boundless. Sections III and IV detailed many communications efforts through multiple avenues to describe the science and beauty of Webb, both prior to launch as well as post-launch using Webb images and data. The focus of the current section explores the potential for future outreach and communications avenues: how can we continue to interpret Webb's discoveries into artwork and text that ensure wide accessibility, and find new ways to reach different audiences? How can a complex topic such as the engineering behind Webb or the astrophysics principles which guide the telescope's observations be best explained to those not from a technical or scientific background, and how can this information be equitably shared across socioeconomic and other barriers? The subsections below explore opportunities to expand future communications in the direction of greater equity and inclusion, drawing upon existing examples as a reference for what can be achieved with Webb outreach.

A. Communications Methods for Equitable Access

Archer et al. [21] proposed the concept of "'science capital' (science-related forms of cultural and social capital) as a theoretical lens for explaining differential patterns of aspiration and educational participation among young people." Science capital is one method to quantify and understand uneven patterns in science participation, and why those who have better access to science enrichment are more likely to pursue career paths in science. Access to science has historically been stratified on lines of gender, race and ethnicity, socioeconomic status, and English literacy, as English is commonly recognized as the language of international science[22]. Those with low science capital and early exclusion from science participation can impact their lifelong access through higher education and the workplace, often carrying through subsequent generations as well[23].

In communities that have historically had low Science, Technology, Engineering, and Mathematics (STEM) participation, often the first barrier to access is the perception of who performs science or engineering. Reinforcement through outdated educational content or popular media of what a scientist or engineer "looks like" has overwhelmingly skewed public perceptions about what specific gender or skin color occupies these technical positions[24]. This perception is even greater in the space industry, where iconic images from the 1960's Space Race era have established a strong baseline for a specific look to traditional astronaut or mission control engineer roles, and many women and minorities may find jobs in these fields inaccessible to them[25]. In science outreach, one common method to combat this perception is through re-centering of historical context. Sharing knowledge that women have participated in astronomical observations and research at such prestigious facilities as Yerkes Observatory[26] and Harvard Observatory[27] and have made groundbreaking discoveries for over a century (e.g. Annie Jump Cannon, Henrietta Swann Leavitt, and Cecilia Payne-Gaposchkin), or that early computer programmers were commonly women and their work was critical in the Mercury, Gemini and Apollo programs[28] (e.g. now famously Katherine Johnson, Dorothy Vaughan, Mary Jackson, and Margaret Hamilton), can change perceptions about who traditionally works in scientific fields and about contributions that women have made towards scientific and technological progress. Many of these women have been either erased from history, or had their work diminished or ignored, with men receiving the full credit and accolades (including being left out of Nobel Prizes). This phenomenon is so common it was even dubbed the Matilda Effect in 1993.[29]

Echoing the earlier mention in Section III, the team that developed the Webb observatory included engineers, scientists, technicians, communicators, and other professionals across 14 countries[30], a truly global effort for the scientific advancement of humanity. In re-centering perception, this diversity has been and can continue to be a strong asset to the Webb communications team. The team has aimed to match speakers of the same gender or a similar ethnic or cultural background to the speaking requests received, which allows for the audience to see themselves reflected in a professional who had helped to build this groundbreaking telescope. The prevalence of virtual meeting software has also greatly improved access to speakers; recently, schools in Hawai'i and the Philippines have both hosted direct virtual events connecting Webb engineers directly with their young audiences. The Space Telescope Science Institute (STScI) has aimed to improve equitable access to observation time on the telescope for all proposers, regardless of educational or cultural background[31]. To achieve this, STScI has implemented a dual-anonymous proposal review process, where the identities of proposal teams are hidden so that reviewers can only focus on the scientific merit of the proposal.

However, these methods still do not completely address equitable access for those who do not have high "science capital", and who do not have the privilege of widespread and easily accessible technical or scientific enrichment. In this context, blending art and technology is an important mechanism for bridging this divide. For art, efforts can be concentrated on creating virtual spaces which blend immersive visual and audio experiences with scientific themes; these both engage the viewer and allow for access from anywhere in the world with an internet connection.

Sponsorship for murals, especially for those that promote astronomical themes based on Webb's discoveries, can also make art more accessible to diverse communities. Murals have been an excellent method of science communication in both Philadelphia, PA[32] and Madison, WI, especially when QR codes are embedded in the artwork as a vehicle for further engagement[33].

The art campaigns run by Masetti reached people from around the globe. Since anyone could participate, regardless of language or location, the #UnfoldTheUniverse and #JWSTArt web galleries[34] contain submissions from places outside the United States, including Lebanon, Hong Kong, India, Philippines, Brazil, Iran, South Korea, Turkey, Greece, Argentina, Italy, Germany, Australia, the Czech Republic, and Egypt. Participants ranged in age from toddlers to seniors, and even included the contributions of an entire classroom of small children from Maldives. Though the barrier to entry was very low, and though art does seem to be a universal language, participants still required an internet connection and a digital camera.

Masetti's art campaigns were purposefully inclusive of all mediums. Art is not just limited to traditional visual mediums as well; dance, music, or other forms are equally valuable interpretations of scientific data. Utilizing platforms or physical spaces that allow hosting of non-traditional art forms can help overcome challenges with access to technology.

One additional avenue to increase equitable access is by bringing support groups and technical hardware to underserved communities, as this can be an inclusive medium for participation and increase tangibility and interpersonal ties to those who are new to the technical community. The Lady Tech Guild [35], formed in 2015 with Zelinskie as a founding member, is dedicated to increasing the presence of girls, women, and female-identifying/non-binary individuals in STEAM fields. Zelinskie and her co-founders were frustrated by the lack of women working in the tech space, especially during the tech boom in New York City, where the Guild is located. Each of the eight founders remembered being "the only woman in the room," something that leads to marginalization or tokenism. In response, the founders started a support network where they came to each other's events, happy hours, meetups, lectures, and any event that they assumed they would be singled out for gender. This then evolved into the eight founders hosting formal meetups where they invited women, girls, and anyone who identified as female to network. Through their meetups they encouraged their members to share their struggles, job opportunities, skills, and emotional support, and this led to collaborations and success stories. A new phase of the Guild's success came with ONX sponsorship: previously, the Guild held meetings at a bar in Brooklyn where each member had to pay for beverages or a private table. When ONX Studio agreed to host and provide snacks and beverages, this allowed for much more equitable access to those who don't drink or can't afford a bar tab– often the ones who need the most support. Currently, the Guild is exploring the possibility of offering meetups all over New York City to make travel easier for those in different neighborhoods, and for those who have caretaking responsibilities. This also allows the Guild to capitalize on all the great tech, art, and science spaces New York has to offer. In addition, the group also organizes charitable outreach in other countries. Sponsor Asha Jadeja flew Lady Tech Guild members to India to share their skills with the girls attending Makerfest in Ahmedabad. Ulimaker, the 3D printer company, helped sponsor 3D printers to give to schools after Guild members taught the girls how to use them. This created a new dynamic in which the boys in the school would need to ask the girls on how to use the tech, flipping the traditional dynamic and shifting the power structure.

As described above, investments in technology and focus on forming interpersonal relationships can increase the science capital of underserved communities, and should be a focus of future Webb outreach efforts. In the next subsection, art is explored in the context of being an important conduit by which these communities can feel included and can connect and retain interest in long-term science engagement.

B. Communications Methods for Inclusivity

Inclusivity in communications recognizes the different needs, abilities, and perspectives of all individuals, and aims to make the knowledge one is hoping to communicate accessible to the largest possible audience. An avenue for communication to ensure inclusivity is via adherence to the principles of Universal Design, which can be applied to visual, audio, and text-based communications[36]. Universal design, at its crux, is defined by the United Nations Convention for the Rights of Persons with Disabilities as "the design of products, environments, programmes and services to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design." The Center for Universal Design at North Carolina State University identifies seven guiding principles for Universal Design; of these, "simple and intuitive use" and "perceptible information" may be the most applicable to Webb's communications.

"Simple and intuitive use" implies that the design is "easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level." For example, artwork may choose to increase its cultural accessibility by avoiding portrayals of humans or animal figures, as these are considered taboo in many countries where Islam is the dominant religion. Zelinskie created the work "US Hexahedron" for the US Consulate in Saudi Arabia, as part of the US State Department-sponsored Art in Embassies program[37]. Consistent with the regional sensitivity to portrayals of figures, the hexahedron's faces are composed of laser-cut hexadecimal and binary codes on aluminum. Zelinskie takes accessibility one step further with this artwork, part of her "Reverse Abstraction" series, by making it accessible to machines as well, as the code describes for a machine the object that the human is seeing. This exploration that humans and computers perceive the world through different languages, and what is tangible for one is abstract to the other, serves as an outstanding metaphor for contemplating universality. The wide appeal of Webb's discoveries also provides an abundance of content for exploration of these themes: for Webb communications, an option is to focus on the naturally recurring patterns within many celestial objects, itself a symbol of beauty in many cultures, and tie to the science behind why galaxies assume the elliptical, spiral, and barred spiral shapes we see today, or why at the largest scales the universe appears almost to be a neural network of galaxy clusters.

Written or spoken communications have different methods to promote inclusivity in the context of "simple and intuitive use." In these types of communications, universality may imply avoidance of colloquialisms or analogies which relate to a particular region or cultural background. One common example is that the Hubble Space Telescope is often compared in size to a school bus, and although school buses exist across the world, the specific size that is being referred to concerns school buses in North America. The surface area of Webb's sunshield is often compared to that of a tennis court. While this sport is played globally, primary popularity exists within Europe, North America, and Australia. Specific references to physical dimensions, temperatures, power values, or other engineering and mathematical quantities may aim to express the same quantity in multiple units and measurement systems, as these reflect regional differences as well.

The second mentioned principle of Universal Design for Webb communications, "Perceptible information," implies that the "design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities." Artwork that incorporates or combines multiple modes for communicating and reinforcing the same information, including through visual, verbal, and tactile means, may allow for the greatest accessibility to those with sensory limitations. In addition to creating sonifications, Arcand's team, referenced in Section IV, also has Braille and tactile representations of astronomical objects available, as well as a collection of 3D printings of NASA data.[38] Maximizing contrast of essential information and its surroundings may provide greater emphasis to those who are visually impaired.

As discussed in Section IV, Webb's images are acquired in infrared light. As such, they need to be colorized, with specific infrared wavelengths mapped to a human-perceptible color. Science visuals developers at STScI, who do this work of transforming Webb's black and white data into stunning full-color imagery enjoyed worldwide by the general public, use both art and science to emphasize features that they would like the viewer to focus on, as well as determine the orientation of the image that would be most sensible to the viewer[39]. Webb's images are colored by using chromatic ordering. Shorter wavelengths are blue, and longer wavelengths move towards red. Alyssa Pagan, one of the two science visuals developers who worked on Webb's first images, told The Verge that the colors chosen are representative of real data. With the right knowledge, both scientists and lay people can read them like a map. In Webb's image of the Carina Nebula, for example, it's clear that the lower red portion is dominated by hydrogen and sulfur (whose signatures are visible in shorter wavelengths of light), whereas the upper blue part is dominated by oxygen. Reports The Verge, "It's after these base colors are applied that things become 'a matter of taste,' says Pagan. She might shift the whole palette up or down the spectrum, making blues appear more purple or vice versa. The contrast will likely be raised, as in the case of the Carina Nebula, making the complimentary colors pop. There are more objective changes made, too, like cleaning up any artifacts like scattered light produced by the telescope, but at this point, two processors may come up with different images. 'I particularly enjoy making things feel more ethereal and magical,' says Pagan. 'There's a whimsicality to my approach — because it's space!'"[40]

As Webb communications move forward, building upon the work already described in Sections III and IV, the tie of Webb data to mediums that transcend language, culture, or even the visual - like music, sonifications, and physical sculpture - becomes ever more important. Webb provides a wealth of material for a science communicator to source from; when a focal point from the outset is to ensure the greatest possible audience for communications, the content that is developed becomes more inclusive to all.

VI. Conclusion

Here we have outlined methods by which artistic interpretation, inclusive practices, and creative use of technology have allowed greater communication and a wider audience for Webb's discoveries. An overview was presented of artist Ashley Zelinskie's most recent works tying in international collaborations with ESA and expanding Webb to a traditionally non-technical demographic with the Texas Eclipse Festival. A summary of Masetti's extensive outreach efforts were presented, including using art as a tool to transcend language and culture, and translations of Webb facts into different languages (including ASL). In addition, the work of other groups within NASA to provide accessible means of accessing NASA data, including that of Webb, were highlighted. Future paths for equitable access and inclusivity were explored, with the following themes being prominent:

- Equitable access can be enhanced by blending art and technology in innovative ways
- Scientific and technical coInterpersonal connections, and re-centering of what what a scientist or engineer "looks like" is essential for underserved communities
- Bringing technology and physical meeting spaces to communities with lower science capital increases the potential for long-term engagement.
- Adhering to the principles of Universal Design can help make Webb's data more inclusive
- Art that appeals to more than one sense can improve its accessibility

By embracing our common humanity across lines of language, culture, and ability, and by continually thinking of creative ways to blend art and technology to expand our audiences, scientific communication can transcend borders and be a transformative and positive force worldwide.

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