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Sustained public engagement in science and engineering via digital spaces and communities

Prepared by: Reyhaneh Maktoufi, *Howard Hughes Medical Institute*

"Is it better to walk or run in the rain?" This is a question that perhaps many people have asked themselves while attempting to stay as dry as possible when caught in the rain without a jacket and umbrella. It is also a question that the YouTube channel MinutePhysics answered in a 2-minute-long video published in 2012 that has since accumulated 20 million views as of spring 2025.

The title of the video elicits curiosity, the content attempts to teach audiences about physics, and the conclusion provides the audience with a solution, showing how understanding science can benefit people — even to answer the simplest questions. The producer has reached an audience that they probably wouldn't have been able to reach without access to the YouTube digital platform, and also elicited conversations with over 27,000 comments on this video. One user remarked, "Learnt more from this than physics class" with 3.2K likes. This is just one example to show the *reach* of using digital platforms for science communication and informal science education.

The 2009 NASEM report section on digital environments cites the 2006 PEW Internet and American Life Project, noting that around 20% of participants from the American sample receive their science news from the Internet. The 2024 News Platform Fact Sheet shows that currently, about 84% of American adults at least sometimes get their news (not specifically science news) from various digital platforms. Such a change in digital news consumption shows an inevitable change in the landscape of science communication and education.

The authors of the report raised the question of the impact of internet use for education, and after more than a decade of research since the report, there is evidence on the positive impact of digital media on science learning and engagement. There are also findings on the negative implications of these digital spaces, such as the easy spread of misinformation, a phenomenon not discussed in the 2009 report.

In this paper, I will review some of the topics discussed in the previous report, such as gamification, while also covering new technologies that have been used more widely in the realm of science education and communication on digital platforms, such as image and video-based social media and immersive technologies.

To do so, I will use the Strategic Science Communication model (Besley & Dudo, 2022) to explore how digital platforms have become increasingly effective spaces for informal science education and the considerations and challenges that creators and educators on these platforms must make when using these platforms for science education. The Strategic SciComm Model, also applicable to engineering and other fields, asks a strategist to focus on:

- **Goal:** a behavioural change that they hope to see in a specific audience. This could range from choosing a career in science to making a healthy choice, or even trusting a scientist as an act of making oneself vulnerable.
- **Objectives:** feelings, frames, and beliefs that need to be changed in order to reach the goal. These could include showing the benefits of a behaviour through **education**, eliciting a feeling of hope to encourage an action, or framing an environmental solution around financial benefits.
- **Tactics:** the engagement details and logistics needed to address an objective. Those can include the message content, style, tone, platform, timing, etc.
- **Evaluation:** measuring if the content had the impact it was intended to have in reaching the goal and prompting a behavioral change.

All of these are in the context of a **specific audience** rather than the general public. Many teachers and educators have specific behavioural goals in mind for education such as demonstrating mastery of a concept or topic, encouraging students to consider a career in science, or helping students make science-informed decisions. One of the first considerations that creators developing science content for digital platforms must make is regarding their targeted audience.

Audience

Who is the audience?
What do we know about them?

Digital informal science outreach spans across a variety of platforms, each with its own affordances and audiences. These platforms have allowed communicators to reach individuals who might not traditionally be the audience for science education and media outlets. For example, the make-up and beauty content on digital platforms can be an effective place to reach audiences that are not searching for science content but can be exposed to science, scientific advice, and debunked pseudoscience claims, like what "cortisol face" is.

These platforms also improve access for more science communicators from different backgrounds to also engage in outreach. This is especially important since, in some conditions, when audiences perceive the source of information to be similar to them, they are less defensive about a message and more open to it (Song et al., 2018 & Kim et al., 2016).

While broadcast television or radio were some of the more gatekept mediums for mass science communication in the past, social media has provided a space for more people to be included in informal outreach and education. This widened access also includes communicators with

limited accessibility, those who could not geographically reach their audience, or those who do not feel comfortable engaging in person.

Knowing each digital platform's main audience *and* missing audience can help creators strategize better for which platform and message tone is the right one for their audience. Knowing the interests and needs of those audiences will also help creators shape the content and tactics. A 2021 survey by Landrum highlights this point: The survey explores the different science topic preferences of different generations,*(*e.g., Gen Z is most interested in psychology*)* (Figure 1), the generations' digital platform preference for public science media consumption (e.g., Gen Z audiences who have a high science curiosity most frequently use YouTube*)* (Figure 2), and missing audiences of different platforms (e.g., Gen Z is a missing audiences for science podcasts).

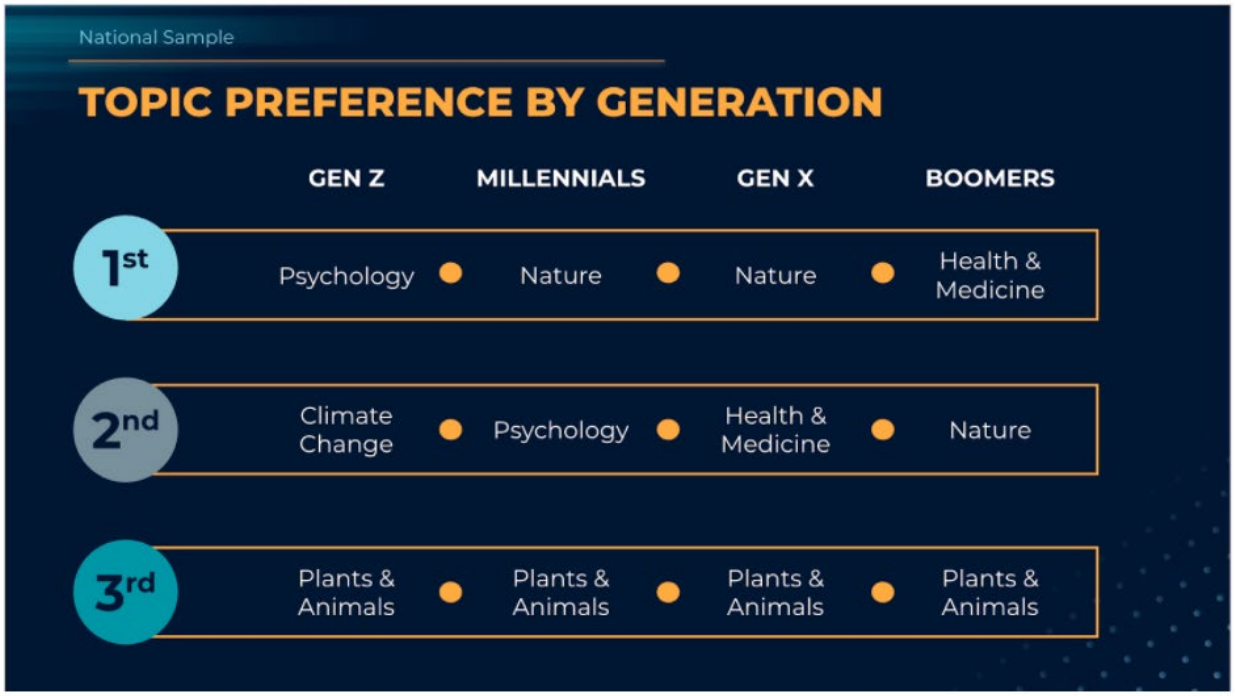

Figure 1: "Influencing Millennial Science Engagement: A New Survey in 2021" Asheley Landrum

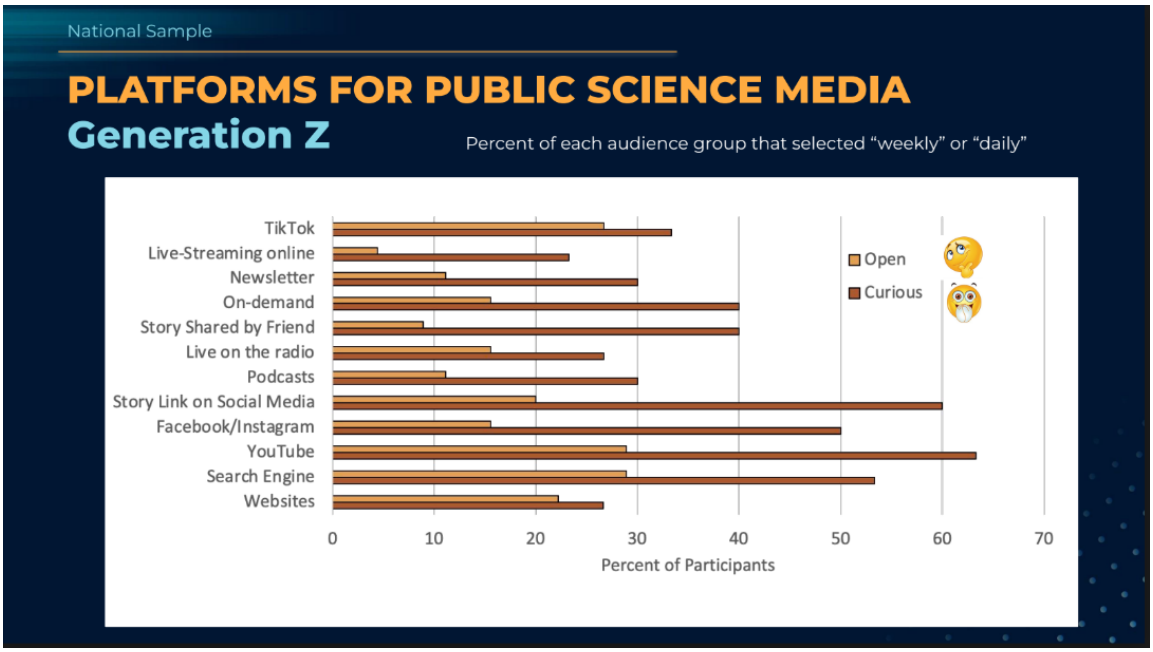

Figure 2 Figure 1: "Influencing Millennial Science Engagement: A New Survey in 2021" Asheley Landrum

Based on this data, if a creator's target audience is Gen Z viewers who are already curious about science, they might want to choose topics in psychology and host them on YouTube, and possibly invest less in a podcast.

Studies like that of Wang et al. (2022) go more in depth into a single platform, showing that science content on healthcare and trivia-style content are more attractive to Chinese TikTok audiences whereas agriculture, social science, and engineering elicit less engagement. However, there are not many updated studies exploring more audience trends for science content on different platforms, which can be of great value to creators.

Alternatively, creators can use non-science social media trends such as Pew's 2024 "Social Media Fact Sheet" to learn more about different platforms' audience demographics. Based on such data, for example, for an older audience aged 65+ with lower income, Facebook and YouTube are ideal platforms. Particularly helpful for K-12 education and outreach might be the 2022 PEW report (Atske, 2022) on teens' social media consumption, showing YouTube's lead followed by TikTok, Instagram, and Snapchat.

While such data can provide creators with information to make choices for their content, there are many other ways to know one's audience, including demographic analysis of existing posts' engagement, talking directly to audiences, observing behavior, etc. Some creators frequently ask their audiences about the content they are interested in and continue to monitor feedback for any changes needed. Another strategy is to tune into viral conversions and trending topics. During the COVID pandemic, for example, science communicator Samantha Yamminee, who

mainly posted content on neuroscience, created content informed by her own and other researchers' expertise that educated the audience on specific COVID-related questions. This pivot to what the audience was interested in and needed the most seemed to have led to more engagement and views of the content at the time. In-person learning spaces like museums also use digital spaces to engage their audience, understand their curiosities, and answer questions. One such example is Emily Graslie's channel, The Brain Scoop, initially hosted by the Field Museum, encouraging audiences to ask questions and providing them with relevant content.

Once a creator knows more about their audience, they can design impactful content that addresses their goals: the behavior they hope to see in the audience.

Goals:

What is it that you hope your audience would do?

On digital platforms, like any other platform, goals can range from encouraging audiences to make a science-informed decision, like helping parents vaccinate their children, to more long-term action-focused goals like encouraging young girls to choose STEM careers. There might be specific goals strongly associated with improving science literacy, for example, a 2007 NASEM book chapter on educational goals *(Taking Science to School*) points at the importance of literacy and K-12 education to develop students ability to engage in critical thinking and problem solving, make evidence-based decisions, choose careers or hobbies in science, and to make the country economically competitive and thriving.

Some of these big-picture goals can be inferred by observing social media feeds of communicators and, at times, specific posts. For example, Emily Callandrelli, @TheSpaceGall, creates content for Instagram, YouTube, TikTok, podcasts, etc. Throughout her posts, there are many themes around encouraging careers in STEM for young girls and encouraging parents to do science experiments with their children on a routine basis. However, she also has more immediate behavioral goals like raising money for the Children's Home Society of West Virginia or advocating to pass the Bottles and Breastfeeding Equipment Screening (BABES) Enhancement Act, initially by sharing her story of being mistreated at the TSA when trying to take her breast milk through an airport.

Many of these digital-based behavioural goals rely on collective actions. Some are more advocacy-centered, like the TikTok-based campaign to collect signatures for saving the Arctic Wildlife Refuge by targeting Gen Z and influencers like Charlie D'Amelio. Others benefit from the scientific process, like that of Zooniverse. Based at the Adler Planetarium, this platform hosts a variety of citizen science projects to encourage their audiences to help researchers in different stages of science, from data collection to analysis, reaching over 887K classifications as of May 2025.

Asking audiences to be vulnerable, trust the communicator, and change a behavior or engage in a specific action is no easy task. However, digital platforms offer the communicator an

opportunity to build a trusting relationship through long-term engagement with their audience if done right.

Hank Green of SciShow, for example, has been a popular source of educational content since 2007 on YouTube. Through the years, he has not only provided his audience with constant learning opportunities, but he has also shared major, authentic, and vulnerable moments, including his feelings and thoughts as he went through a cancer diagnosis and treatment. His audience engages with him in different ways, such as tagging him in various social media posts to ask him to fact-check and explain the science content, investing in Hank and his brothers' initiatives, and staying loyal consumers of his content. These interactions are especially important since they provide him with an opportunity to identify misinformation that needs addressing. In a BlueSky post, he claimed that being "authentic" has contributed to his trustworthiness as a credible source of information.

One affordance of media is to help build a parasocial relationship between the communicator and the audience. Parasocial relationships, introduced by Horton and Wohl (1956), are known as a one-way relationship between a media personality and a media consumer, where the audience might see the personality as a friend or find some sort of bond or intimacy with them. Parasocial relations can influence attitudes and behaviour, and studies have shown their impact on trust in the personality as well (CITE). This idea has also been explored in the science communication realm, pointing out that scientists as influencers can also engage in self-disclosure and other tactics to build a connection with their audiences (Zhang & Lu, 2023).

Objectives:

What are the immediate beliefs and feelings we want to impact?

A study by Besley et al. (2016) shows that knowledge-building is the main objective of science communicators. Similarly, a 2021 (Maktoufi) landscape analysis shows that many visual media-based science content creators believe that eliciting positive emotions, making the scientific process transparent, and improving knowledge are their most important objectives. This focus on learning and **education** is reflected through the science content on digital platforms as well.

Some of the most prominent channels and brands of STEM learning, like Khan Academy or the Green Brothers' channels, have been around for almost two decades. As noted by Miles et al. (2024), it is surprising how little research is available on YouTube and education, considering YouTube's wide use by teenagers and extensive student access to smartphones. I might add how even fewer studies seem to focus on YouTube and its use for informal learning outside the school context.

In situations where the production goes hand in hand with classroom resource production, there are also dedicated resources that can be used as a complement to media content for better learning outcomes, like discussion questions, problem-solving activities, and gamification of the content. Examples include the PBS Wild Hope series, focused on biodiversity solutions, which was the base for BioInteractive's Wild Hope educational content design. This educational

platform for biology education provides lesson plans and comic-based activities to facilitate the use of the media for formal education settings.

Khan et al. (2019) describe that many college and high school students voluntarily use YouTube to learn about topics from their science and engineering classes. The students primarily cite not understanding the teachers' lectures as the main reason to use YouTube, followed by the unhelpfulness of textbooks, improved learning by visualizations of complex concepts, and missing lectures.

A 2024 meta-analysis (Wu) examining the impact of digital technologies on deep learning, however shows that while digital technology improves deep learning for humanities, social science, and natural sciences, educators can improve impact by coupling offline learning and online learning, focusing on collaborative learning, using proper instructional guidance, and taking a cohesive approach to using the technologies.

This shows the importance of educators' intentionality when integrating digital technologies in their classroom and considering a program that carefully makes space for these technologies in specific formats, spaces, and with appropriate instructions. A similar approach can be considered when integrating digital media in informal curated learning spaces. The analysis also points to 13 out of 60 studies that show the negative impact of using digital technologies in education. The author notes the importance of examining different contexts, such as "misaligned instructional strategies."

The objective of education also goes hand in hand with improving the sense of **self-efficacy**, helping audiences know how to do the behavior the communicator is advocating for. For example, AsapSCIENCE primarily educates their audience not only about science fun facts but also about ways they can have a more positive impact on their environment. Creators also use other creative and engaging ways to build that efficacy, such as this list of "inappropriate CPR songs" or Dr. Ayana Elizabeth Johnson's Climate Action Venn Diagram.

While some of the educational content is used for building self-efficacy or informing the audience of more neutral facts, some is specifically used for **attitude change** to highlight, for example, the benefits of engaging in a science-backed behaviour or the harms of avoiding that behavior. This type of content was especially prevalent during the COVID pandemic, with many communicators discussing the benefits of vaccination and/or the impact of vaccine hesitancy. Even the singer Olivia Rodrigo used her influence to encourage vaccination via the White House YouTube channel.

Other forms of education focus on **norm-building**, showing that a recommended behaviour or a condition might be one experienced by many people, thus encouraging the audience to engage in a specific behavior, especially when there is stigma associated with those, such as ABC Australia's IBS PSA via Hot Girls Have IBS. Showing audiences that a recommended behavior is performed by other individuals similar to the audience is an effective way to encourage a behavior (e.g., Yamin et al., 2019).

Digital media is an excellent place for **eliciting emotions**, including positive ones such as amusement, hope, and pride (discussed by Nabi & Qi, 2022). Creators The Black Forager and Ze Frank not only educate their audiences on topics like foraging or animals, but also seem to aim to elicit **amusement** as well, talking about leaving the leaves with the "grass is trash" jingle or angler fish looking like "a rainbow…of ugly!" Humor, if used appropriately, for example by using self-deprecating humor (Bitterly, 2018), can also improve how the communicator is being perceived (Yeo et al., 2020) and can be an important impression-management tool. However, it should be used with caution, especially when communicating specific health behaviour, considering how humor might make the issue seem less serious (discussed by Nabi & Qi, 2022).

Eliciting **hope** is another positive objective. Content like the How to Save a Planet podcast or the PBS Wild Hope series focuses on conservation success and solutions, and on injecting hope, which can mobilize audiences towards action if designed appropriately. For example, a 2023 meta-analysis on hope and climate action (Geiger et al.) points at different aspects of hope that can be more harmful than helpful, such as the hope that a problem is not as serious (Ojala, 2012).

The emphasis on eliciting hope and positive emotions does not mean emotions with negative valence should be avoided, but rather used with caution and paired with the appropriate message. Many creators show their **vulnerability** and humanity by sharing their stories of grief, loss, anger, etc. For example, Alyssa Paparella, the founder of Disabled In STEM, shares many moments of vulnerability as a student with a disability in the STEM field, grappling with topics of discrimination, chronic pain, and isolation. Dr. Raven Baxter is another example of showing vulnerability by sharing her experience of graduate school isolation or the impact of her long-COVID on her life.

However, other negative feelings like **outrage** (with anger as a component) can be more controversial emotions to address. As Brady and Crockett (2019) discuss, while online outrage can be effective, it can have many negative consequences, such as reduced strategic thinking and consideration for long-term impact, and oversimplifying complex challenges.

An important SciComm goal is to build trust with science and scientists. In their book, *Strategic Science Communication*, Besley and Dudo (2022) discuss objectives that connect to trustworthiness goals, including showing warmth (care), showing competence, integrity, openness to listening, and shared identity. Due to its direct access to audiences, if chosen, a casual and authentic style, and its live and interactive features, many digital media platforms can possibly contribute to fulfilling these objectives.

As mentioned, many creators can show that they are not different from the audiences and have shared values by showing vulnerability and telling personal stories, others build warmth using humor, or show that they are willing to listen by addressing audience questions. For example, through trends like #ScientistsWhoSelfie, scientists can improve their perceived warmth and trustworthiness (Jarreau et al., 2019).

By being able to have clear objectives, creators can dive into choosing the appropriate tactics to reach a specific demographic and provide information, elicit emotion, empower action, and manage perceptions.

Tactics:

How are we engaging our specific audience based on our goals and objectives?
Who is the messenger?
What is the tone, style, and format?
What platform are we using?
What is the content of the communication?
What are the logistics?

After identifying one's audience, goals, and objectives, creators can focus on working on the details of an engagement tactic., A communicator might already have a set engagement tactic such as an Instagram account with an established audience that they want to use for science communication, or a funder may be interested in exploring the use of virtual reality for outreach without having determined what it is exactly aimed to do. In these cases, it will be helpful to explore the affordances of tactics and determine the audience, objectives, and goals based on existing opportunities.

This is especially important because, as will be discussed further in this section, different platforms have specific content priorities and preferences with dominant audiences. For example, if a communicator is hoping to use their Snapchat account, they should probably avoid using it to encourage older adults to wear sunscreen, using a serious tone with text-based content. Similarly, a LinkedIn post might not be the most efficient tactic to elicit excitement and joy for K-12 students to pursue careers in science. To choose the right tactics, knowing one's objectives and audience, available platforms, and their affordances can provide creators with a clear guideline on engagement tactics.

One of the most impactful elements of engagement tactic design is **the messenger**. This messenger can take different shapes, including a recurring "host" such as Trace Dominguez, the official host of Star Gazers, the owner of the account, such as Big Manny, the voice of an organization, such as NASA, with no specific person representing the content, or two amoeba sisters, cartoon characters who teach biology.

While non-hosted accounts like NASA are wildly popular (96.5M followers on IG and 12.4 subscribers on YouTube as of Spring 2025), Welbourne and Grant's 2016 analysis of 39 science communication YouTube channels shows that regularly hosted communicators increase video views and can build meaningful connections between the communicators and the audience. These continued connections and relationship-building seem to also create communities of fans like the Nerdfighters, the community surrounding John and Hank Green (creators of Crash Course) who aim to "fight against world suck".

Choosing the tone, style, and format of the content can be very personal and depend on the creators' personality, skills, and already-existing platform. However, when the content is made less in the style of user-generated content and more as a part of a brand or organization, it can be more easily tailored to take a specific tone or be housed on a specific platform. For example, suppose a science communicator plans to reach young women and encourage them to choose careers in STEM by helping them believe they can also become scientists. In that case, if he is an older male communicator on Facebook, he might not be the most impactful messenger, with the right platform or the right style. He might decide to choose a different audience for his content or provide resources to another communicator on another platform.

As discussed in the audience section, different platforms have their affordances and might be hosting a higher number of specific demographics. While in the past, platforms had a more specialized type of content they hosted, recently, more platforms seem to be open to a variety of content. For example, X used to be a text-sharing platform only, and the ability to insert images was introduced later to the users. Similarly, Instagram added videos, Stories, and Live streams later in the product development process.

Despite the overlap of formats, there are still significant differences between social media platforms. YouTube, for example, stands out as one that hosts long-form videos, shows, and series. Large brand channels like Seeker use YouTube for their long and short-form content, but personality-hosted channels also share their shows and content on YouTube, such as Brain Craft's Sleeping with Friends, making it a platform that expands science communicators' abilities to produce and share content in numerous ways.

In their book *Perspectives on Emotions in the Digital Age,* Skurka and Nabi (2023) remind their audience of the context of different media and platforms and the range of different expectations the audience has from interacting with different media. For example, watching a long movie involves more engaged emotions and reactions versus being on TikTok and engaging, possibly less meaningfully, with a plethora of short videos. Even the design of a platform, like Meta's different emotional reactions, can impact the audience's reaction.

Considering these variations, a science communicator should consider the context of different platforms in a holistic way, the demographics of audiences or media format, but also how audiences interact with the content, what response options do they have, the current known content promotion algorithms, and the sociopolitical trends on the platform.

Creators might produce text, images, videos, polls, or art content based on a variety of reasons, including their message, audience, or channel aesthetic. This content can come in the form of narratives, news, sharing fun facts, and more. Stories are one of the most impactful forms of science communication delivery. The right narrative can improve learning outcomes, memory, allocation of cognitive resources, and message acceptance (for more, check Dahlstrom, 2014).

Podcasts such as the Story Collider and communicators like Dr. Manning's X account and podcast use storytelling to transport audiences into their experiences and "explore the human side of medicine." For example, in this post, Dr. Manning empathetically describes the

experience of her encounter with a COVID patient who did not receive the vaccine. The experience in some way complicates the narrative of the unvaccinated by showing the barriers and fears individuals might experience. The story prompted other users to share their own experiences in the healthcare system.

Delivery formats like newsletters can combine stories, news updates, fun facts, and other messages in one space and provide their audience with a variety of options for consumption. Other newsletters, such as the Yale Program on Climate Change Communication, mostly focus on reporting findings from their ongoing surveys related to climate change perceptions and opinions, which can be beneficial to individuals who look to substantiate their content with data.

Thus, not all content delivery has to be in a long narrative format; depending on the creators' strategy, other formats might be more straightforward or impactful. For example, microlearning experiences in the form of short educational content on social media or DuoLingo's math courses are brief, engaging content that many creators take part in producing.

Some communicators and educators might even use *visual difficulty* to elicit their audience's curiosity and cognitively engage their audience, opening doors for the process of inquiry-based learning. For example, at the Space Visualization Lab at the Adler Planetarium, scientists would use images, videos, and animations that are vague to some degree, such as stars moving at the center of the galaxy. They will then prompt the audience to ask questions, and the audience frequently points at the difficult-to-interpret visualization and asks, "What is this?" (Maktoufi, 2021) Such forms of message delivery can be a great engagement form. On social media, National Geographic Explorer Reuben Wu uses fantasy-like laser-based light engineering in familiar landscapes in his photography, leading to audiences trying to decode the mechanism behind the capturing of the image: "Is all that color in the wave from the drone or is that bits of bioluminescence?"

Such different forms of content delivery can elicit different audience reactions. Hüsgen (2017) explores the effect of Facebook's post types on the different forms of audience reactions in marketing. For example, conversation-type posts can help with link clicks, while awareness-type posts can help with likes, comments, and shares.

Similarly, a report on the multiplatform media PBS NOVA's Polar Extremes, comparing a film on paleoclimate science to a digital game with similar content, suggests that material should be designed with consideration for desired outcomes. They noted the different affordances of the video and the game. While there was a difference between learning outcomes for different age ranges, there was a slight difference between learning outcomes from the film versus the game. The film seemed to have a better effect on the audience's engagement, interest, metacognition, and science reflection, while the game had more of an impact on inquiry, communication, collaboration, and identification with science. If inquiry and engagement are the creators' desired outcomes, a game would be a better tactic, but the film elicits more interest in the topic if that were the creators' objective.

Additionally, their findings suggest that a facilitated discussion in a focus group can help participants engage in more reflection around the "why" of the content rather than just describing what they saw, suggesting the importance of moderated conversation alongside consuming digital content.

Another engagement-based NOVA program is the Building Stuff with NOVA's Twitch channel which used the gamification tactic to engage its audiences with engineering concepts and also encourage future career choices (goals). Through gamification of engineering by designing an escape room with their audience, the producers intended to facilitate education and curiosity (objectives).

There are also more immersive spaces that have been developed more recently, like the metaverse technology: virtual worlds where individuals can build spaces, experiences, and interact. Metaverse can be used with or without VR and AR. Roblox, for example, is an online gaming platform with features similar to the metaverse and widely used by Gen Alpha and Gen Z (Han et al., 2023), where users can play and create games.

Science education is a salient part of this platform, with museums, education centers, and individuals creating experiences. In a systematic review, Han et al. (2023) showed that Roblox has a positive impact on the students' "cognitive or noncognitive abilities" such as creativity, math, and social interaction ability. The Boston Museum of Science's work with Roblox to co-create the Mission Mars project is one of many educational collaborations in these immersive universes. Mission Mars allows students to experience what it is like to become an astronaut. In this digital experience, participants will engage in activities such as engineering their Mars vehicle, collecting samples, and engaging in rescue missions.

The youth's interest in popular platforms like Roblox can work as the hook that brings the user in and engages them with science, as shown by a study on Minecraft (Hobbs et al., 2019). Minecraft, similar to Roblox, is a wildly popular gaming platform for the youth, used also by science centers and schools like the San Juan Math, Science, and Technology Center in Puerto Rico which used the platform to teach their students how to create new compounds with considerations for risks of explosion and other features of combining materials.

AR and especially VR might have more limited use due to their reliance on more advanced and expensive devices. Museums are one of the spaces where these technologies are sometimes used, which significantly improves knowledge and skills (Zhou et al., 2022). Institutions like the Smithsonian Museum of Natural History encourage visitors to use their phones, and with the augmented reality show, visitors can engage with aspects of a scientific concept that are difficult to comprehend or visualize. In the Smithsonian's case, the Skin and Bones app used AR to create overlays on animal bones, visualizing how they would look in flesh, and in return improve the visitors' understanding of their skeletal systems (e.g., Chiu et al., 2015).

Portable VR headsets also make it possible for communicators to take their content to different events and where their audiences are. Virtual Planet Technology, takes their rising water level stimulator to different communities for the audience to immerse themselves in a world that

looks different. Studies have shown the impact of VR on increased users' emotional empathy (compassion) (Martingano et al., 2021). Though it should be noted that VR was not more effective in eliciting empathy than other forms of technology.

Some science centers and museums also use digital tools to improve the accessibility of their content, such as audio descriptions of material, virtual tours of their museums, and 3D printing technologies for tactile access to content. AI has also been used for improved accessibility via features such as its content translation or summarization abilities, which also come with a variety of ethical considerations and accuracy challenges.

Similar opportunities and concerns arise as creators use AI to develop images, videos, and captions for their posts, create scripts, develop outlines and interview questions for their stories, or use AI to package large pieces of content into smaller posts to be shared individually. These features can be of great value, especially since many science communicators and informal educators engage in outreach as volunteers with little to no funding, and limited time and resources. However, AI platforms like ChatGPT have proven to be frequently providing users with false information and resources (e.g., Bhattacharyya et al., 2023). There are also major ethical considerations for AI around the use of other artists' work and taking away job opportunities.

Possibly less used and discussed in science communication and learning are digital ways museums, science centers, and public events visualize data and phenomena through interactive visualizations, Kinect control displays, Tangible Bits, and other technologies. These technologies allow visitors to connect the digital and physical world. As Ishii and Ullmer (1997) note, the Tangible Bits connect "both cyberspace and the physical environment" (p.234) The Space Visualization Lab at the Adler Planetarium, for example, uses the WoldWide Telescope's motion sensing technology to allow audiences to move through the universe with the control of their hands. These motion-sensing technologies seem to help students, especially with their motivation. (Chang et al., 2017; Hung et al., 2017)

Despite the discussed affordances, with the changing sociopolitical landscapes associated with different platforms, ongoing algorithm changes, and platform updates, it is hard to keep track of which platforms can be most beneficial for which audiences, objectives, and goals. While X (formerly Twitter) was one of the hubs for academics to have conversations with their audiences, recently, some academics and researchers have migrated to alternative platforms like Bluesky and Mastodon, with limited studies on their role in science communication and outreach. This fast-paced, changing landscape demands constant evaluation and review.

Evaluation:

Did we have the impact we wanted to have?

While social media provides creators with metrics that can determine some level of reach and engagement, such as likes, shares, comments, and views, it is harder to measure specific objectives and goals, such as a shift in attitude or change in behavior. While the 2021 landscape

analysis of visual media-based science content creators' use of the science of science communication (Maktoufi) shows that most creators use social media metrics, views, and anecdotal evidence like emails and comments as a way to measure their impact, a very small percentage of them use academic research collaborations as an impact evaluation strategy.

Social media creators can use the standard metrics of their platform to determine what type of content has been more engaging and successful. Platforms like YouTube even provide creators with A/B testing of their video thumbnails and YouTube Analytics tools, with the opportunity to look at the content's audience and their interaction with the content. Analytics also allows creators to see audience retention and when they stopped watching. This can help them identify specific hooks, visuals, or story structures that keep their audience watching. However, to examine, for example, whether a video leads the audience to consume less meat and opt for vegetarian food, the content producer would need more resources.

When resources are available, some collaborate with researchers and evaluators to specifically measure the impact of their content. PBS, for example, does so through NSF-grant collaborations with researchers. A good example is Deep Look, a YouTube-based video series produced byPBS station KQED and PBS Digital Studios. Through the NSF-funded project Cracking the Code: Influencing Millennial Science Engagement, researchers from Texas Tech University and Rockman et al. collaborated with the program to examine how to best engage younger and more diverse audiences.

In one of the studies (Landrum, 2021) from this project, the research looked at women's preference for the video title and thumbnail and the connection between women's preferences and their science and social identity. This information can help creators produce content that appeals to more women, considering the lower number of women consuming science YouTube content. Landrum highlights three YouTube channel examples: It's *OK to Be Smart*, *Physics Girl*, and *Space Time*, all with more than 75% male viewership (please note the stats are from when the study was conducted in 2021). These forms of evaluations can provide suggestions to improve such numbers and create relevant content. This study suggests that women might be more motivated to seek science content for informational purposes rather than satisfying a curiosity or entertainment (Landrum, 2021) . Interestingly, the grant also examined what research-practice collaboration looks like, providing a visual process of what to plan and expect.

Creators might also use direct and indirect ways to measure their impact. In 2024, The Physics Girl, who had been struggling with the impact of long-COVID, hosted an online fundraiser for long-COVID research, raising over $131K in funds. Others might use indirect measures. For example, creators might encourage their audience to learn more about the impact of pesticides and add a resource in their Link in Bio and monitor how many users click on the link to learn more about the content. While these types of measures might not be very accurate, they give creators a baseline to compare what content might elicit more engagement and move audiences to some form of action, even if it is to read more about a topic.

Informal conversation and connections with community members and audiences should not be underestimated. For example, the NEWF program, training the next generation of African

science storytellers, frequently works with science communicators who produce content and outreach programs for their own communities. Being embedded in the communities helps them form narratives and programs that address community needs, but also facilitates the sharing of content back to them with immediate and direct feedback from them.

For example, Explorer Home: Madagascar Science Center, a program to engage the youth in STEM and elicit enthusiasm through moving science bus visits, nature excursions, podcasts, and more, has been deeply informed by community needs and input. The program was envisioned by Dr. Tsiory Andrianavalona and Dr. Ramihangihajason Tolotra Niaina, who took into account the needs of their community and, in one of their projects, set up the SciTia travelling lab.

They recall that in a school feedback process after a session on water, the dean requested a curriculum on cleanliness. The dean pointed out that the "science side of it" will be more convincing for the community if the students can learn the topic and share it. The request gave rise to a soap-making curriculum based on ingredients that can be found in their community. The students loved the program and even went on to make experiments on their own by adding dye and scent. Additionally, while the team has a database of short videos they use in education, in this case, due to limited electricity, they printed the content and shared it with students for easier access.

Eventually, the students will present the products and explain the scientific process of saponification during a fair organized by the church in the village. In this case, the community-informed outreach elicited participant interest and produced buy-in from the larger community.

Challenges

Many of the impactful affordances of digital and social media are also parts of their challenges, both for the creators and the consumers of content. While there are conversations surrounding creators and users' roles in addressing these challenges, such as the spread of misinformation, as discussed by Scheufele et al. (2021), this would be similar to blaming the chess player who lost to a supercomputer competitor. While creators have a significant role to play in creating high-quality and impactful content, misinformation's spread is heavily influenced by algorithms and user engagement, leaving the platforms mainly responsible for how this information spreads.

As mentioned before, messages focused on outrage can hinder strategic thinking and erase nuance. These features work opposite of what the Solutions Journalism project advocates for: Complicating Narratives. In other words, creators have to compete with bombastic and polarizing content that is easy to consume when trying to build a complete picture of a nuanced issue that elicits critical thinking and might not provide audiences with a straightforward answer.

Misinformation, disinformation, and their spread through social networks might be one of the most salient challenges in the landscape of digital media today. Additionally, with the fast spread of AI and its integration into all aspects of life, questions surrounding the ethics of AI

use, especially the intellectual rights of the content created by AI. The AI-assist outputs should also be used with caution since there have been different instances of AI creating fake citations and misinformation. A study by the Columbia Journalism Review (Jaźwińska & Chandrasekar, 2025) examining the accuracy of citing responses among a range of AI-assist tools has shown inaccuracy in more than 60% of answers, with Grok 3 having a 94% error rate. The responses were mostly provided with very little intellectual humility (expression of the possibility of being wrong), where the premium versions of the different tools displayed even more confidence in the inaccurate responses.

Accessibility of technology is another challenge, considering not everyone has access to digital media, especially as they become more niche, such as VR headsets. Once these technologies become a part of a widespread initiative, communities with limited access can be left behind. This elicits the strategic question of does the audience have access to the technology, is the technology necessary for the project's objectives, and if it is, what is being done to ensure access?

This is especially important since the use of the latest digital media can be a sign of status, where instead of deciding on the most impactful tactic, the tactic of using VR or other high-tech tools determines the rest of the project. This does not mean that communicators or educators should not use these latest technologies, but rather it means that they should be more intentional about the technology's presentation if it is a crucial part of their project. For example, The Mind Museum in the Philippines hosts an ocean-themed light festival in Manila near the downtown mall and shopping center where multiple puppets of sea creatures adorned with colorful lights interact with the public. While such tools can be placed in the museum, in order to access audiences where they are, the organizers took the content to the popular malls.

Another challenge inherent to social platforms is bullying and harassment. For example, Han et al. (2023) discuss the possibility of not just cyberbullying, but also security issues when using Roblox. This is especially important since around 21% of children who use Roblox spend an average of 10 hours a week on the platform (Statista, 2022), which can also elicit worries around screen-time use by the youth and its impact on both physical and mental health (e.g., Muppalla et al., 2023).

Many creators, especially women, are also the target of cyberbullying. A survey by Global Witness has shown that about half of climate scientists online with more than 10 publications have encountered abuse, especially on X (Twitter) and Facebook. Women, particularly, had to deal with more harassment targeted at their appearance and have been threatened with violence. Emily Grasley, the host of BrainScoop, discussed the topic in her video "Where My Ladies At?" highlighting the different aspects of such harassment, from questioning women's credibility to extremely inappropriate sexual comments.

Race can be another contributor to forms of harassment (Royan et al., 2023), as mentioned in the case study in the same report. Dr. Dasgupta talks about his experience of racism and receiving abusive private messages. The author of this white paper who created and hosted Sciencing Out, a PBS digital series on women in science communication also had to deal with

reading comments like "[...] the presenter can be unintelligible in her speaking patterns. I'm disgusted and I've turned it off after 5 minutes" which is a familiar experience to many creators who are personally attacked in comments by viewers. These sorts of harassment, especially for creators from marginalized identities, can possibly be a barrier to participation in content creation.

At times, the same features that improve the impact of a creator's message can be the cause of their distress. As discussed previously, social science research has shown that many of the prolonged connections with the host through social media, videos, and podcasts can help with parasocial relationships. While these relationships are great for building trust, they can have a deep negative impact on the communicator as described by Alexis Nicholes (The Black Forager) in terms of boundaries and personal space. In a post, she describes that the established relationship might embolden audiences to approach her in the real world and in distressing ways.

These are just a few challenges associated with digital media and the landscape of science communication and education. Perhaps one of the most important concepts to remember is that "Change moves at the speed of trust" (Covey, 2008). While creators and communicators might plan to use the latest exciting technologies in their endeavors, they should ask the important questions about the ethical and actual cost of the technology, public trust in that technology, and who will be left behind when using that technology.

Conclusion

This landscape report uses a "strategy" lens to review a variety of existing science outreach and education programming and platforms, their affordances, and the science behind them. While not a comprehensive list, the report aims to address some of the most commonly used platforms and formats in digital spaces. Some of these were not covered significantly in the 2009 NASEM report, such as social media platforms, while others, like the gamification of science outreach and education, were more extensively discussed.

Perhaps some of the most prominent changes in digital media use since then have been the focus on user-generated content. The increased ability of anyone to create content has decentralized science communication and education, on one hand, empowering more individuals to directly connect to audiences with reduced gatekeeping of who can be a communicator and educator. On the other hand, allowing anyone to create a piece of science content without any fact-checking, leaving audiences to their own devices to evaluate content credibility.

This duality has been met with a wave of educational posts on misinformation, fact-checking, and media literacy to empower users to screen content and be able to identify trustworthy information and creators. Additionally, other creators have even been creating media on how to interact with such misinformation and disagreements on social media, focusing on civil and compassionate interactions around these topics. Organizations such as Good Conflict, for

example, advocate for strategies including complicating narratives and understanding that stories are not binaries and individuals are not simply good or evil, but rather that actions can come from complicated places of fear, shame, and other emotions with a nuanced reason behind them.

With the popularization of AI-assist platforms such as ChatGPT that can provide responses to complicated user requests and the use of AI algorithms in more practices, this landscape becomes even more complicated as AI platforms can integrate biases from the developers and other users' engagement into their responses. *Algorithmic accountability* is an important practice to ensure that these technologies continue to prioritize accuracy and truth in their responses.

And finally, if you started reading this paper wondering if it is best to walk or run in the rain to avoid getting wet, it is best to run.

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