Undergraduate Student Perspectives on a Science Debate Training Activity

Paul Chiu

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Introduction

In the multi-century history of science, its members have started shifting their attention to how they talked about their facts and findings with general, non-specialist audiences (i.e. public science communication) only relatively recently. For example, the four entries in the Social Sciences Citation Index — a multidisciplinary database of over 3,000 social sciences journals — that are explicitly focused on the field of science communication have only begun publishing in 1979 (*Science Communication*), 1992 (*Public Understanding of Science*), 1996 (*Journal of Health Communication),* and 2007 (*Environmental Communication*).

Summarizing developments in the academic understanding of public science communication, Bucchi (2008) — a former editor for the second of these journals — describes how traditional notions from the early 20th century viewed it as a one-way transfer of knowledge. In them, speakers were more preoccupied with the amount of information being given rather than whether their audiences were engaged and receptive to what was being presented to them. Nested in this "dissemination" paradigm (a term from Kappel and Holman [2019]) was the "deficit" model, the assumption that one's ignorance of science and hostility to its ideas could be remedied by the aforementioned knowledge transfer (i.e. the facts will speak for themselves).

However, Bucchi (2008) points out how later research questioned such assumptions. For example, Wynne (1992) had interviewed English hill sheep farmers who had received advice from scientists on farming restrictions enacted in light of the radioactive fallout caused by the Chernobyl nuclear disaster. As opposed to passively following the scientists, Wynne's interviewees distrusted them, mentioning to him how this was based not on the soundness of the science but the scientists themselves. The farmers did not view the scientists as credible based on two of their observations about the latter group: (1) the scientists had previously made confident — but incorrect — assertions that Chernobyl's fallout would not affect England and (2) the scientists seemed ignorant and even dismissive of specialized knowledge pertaining to hill farming with sheep (i.e. the scientists did not appear to know as much as the farmers).

One does not have to go so far back in time to find other cases of what has been described as "science communication failures" by publications such as Kahan (2015) as well as Kahan and Landrum (2017). As the two respectively spotlight, climate change denial and vaccine hesitancy are ongoing science-related issues that have harmful effects on society. For the former, this entails preventing actions that moderate climate change (e.g. reducing greenhouse gas emissions) despite a proliferation and/or intensification of dangerous meteorological phenomena (e.g. heat waves, storms, floods, droughts, forest fires; Haines & Paitz, 2004). For the latter, this refers to ensuring that diseases — specifically human papillomavirus in the context of Kahan and Landrum (2017), but the author's commentary can be applied to (as highlighted by Dror et al. [2020]) the current coronavirus pandemic — continue to spread amongst society.

Such issues continue their harmful influences today despite the virtually-unanimous scientific opposition to climate change denial and vaccine hesitancy (Anderegg et al., 2010; Cutts et al., 2007). After all, as Ali and Celentano (2017) and Brisman (2018) observe, even if scientists can pass along accurate facts and comprehensive studies that present a case for why we (as a collective society) should support efforts for climate change action and vaccination, it may still be unable to sway those with opposing views. Continuing along, the two publications comment that we are in an era that is "post-truth" — defined by *Oxford Dictionaries* as "relating to or denoting circumstances in which objective facts are less influential in shaping public opinion than appeals to emotion and personal belief" (Oxford Languages, 2016).

Even then, there may be other factors for why one would choose to go against such facts. As Ali and Celentano (2017) note, hesitancy can also arise from conflicting recommendations from vaccine providers (akin in nature to the inconsistent advice given by the scientists described by Wynne [1992]) or a lack of access. A lack of information and exposure to misinformation are not the only possible causes for why one would go against the existing science. As such, there has been a recent shift amongst science communication scholars to a line of thinking that is more inclusive of the public (Bucchi, 2008). This "public participation" paradigm (another term from Kappel and Holman [2019]) forewent the one-way nature of the dissemination paradigm, advocating instead a "dialogical" model that encourages the audience to participate in two-way dialogue-based discussions around scientific topics by providing their thoughts and perspectives.

Still, as scholars of science communication lament in extant literature (e.g. Bauer et al., 2007, Dudo et al., 2021; Fischhoff, 1995), just because they are aware of and are adapting to this new paradigm does not mean that others are too. After all, past interviews with researchers in the biological and physical sciences have found that most respondents still subscribed to the deficit model (Frewer et al., 2003, Grubert & Cook, 2017), with this trend holding in larger-scale (i.e. more than 250 participants) surveys of scientists (Dudo & Besley, 2016; Simis et al., 2016).

The latter of these surveys had also highlighted a trend in that researchers who were amenable to the deficit model tended to hold negative attitudes towards social sciences. To improve such attitudes, various literature (e.g. Bennett et al., 2019; Besley & Tanner, 2011; Dudo et al., 2021; Simis et al., 2016) propose that more scientists should be trained in communicating science to general, non-specialist audiences. This is reflected by how most of the researchers studied by Esmene et al. (2017), Grubert and Cook (2017), and Salmon and Roop (2019) reported having undertaken little to no formal instruction on public science communication.

However, in the context of Canada, there is a major bottleneck for fulfilling this proposal: efforts to conduct such training are still in their infancy. Indeed, Schiele and Landry (2012) listed only six Canadian academic institutions offering courses in public science communication in 2012, with these courses having been available only for graduate students. In other words, prospective scientists (i.e. undergraduates) wishing to nurture their competency in public science communication before becoming full-fledged (i.e. working or graduate) scientists would have been unable to do so.

This is problematic because, as Brownell et al. (2013) contend, including public communication into the undergraduate science curriculum would normalize in budding scientists the view that communication ability is something that should be developed in tandem with and is thusly as important as the rest of the core scientific skills (i.e. critical thinking, researching). Limiting training opportunities to only graduate students would paint communication as something that only the most advanced/specialized of scientists would need, thereby promoting an academic culture that views it as a non-essential competency that most students do not need to hold.

Yet, another issue arises. While there may be calls for more undergraduate science communication training, publications such as Mercer-Mapstone and Kuchel (2015) as well as Yeoman et al. (2011) have observed a dearth of literature that focus on it (e.g. by answering questions such as “What should undergraduate training entail?” or “What are some pre-existing examples/cases of it?”). Addressing this deficiency in the literature, this study will be examining an undergraduate science communication training course that is ongoing at an Ontarian university.

To elaborate, this study will focus on a one-off semester-end activity where students participated in a series of in-class debates —both in the role of a debater as well as in the role of an audience member who would vote who “won” in other debates — about various science-related issues/questions. Such an activity was designed as a way to prepare students for future scenarios where they face disagreement during their dialogues with the public (e.g. the English sheep hill farmers [Wynne, 1992], climate change denial [Kahan, 2015], vaccine hesitancy [Kahan & Landrum, 2017]), especially as issues that have been discussed in this activity include those frequently encountered in current public and political discussions of science (e.g. the invalidity of Flat Earth Theory [Paolillo, 2018]; the safety of genetically-modified foodstuffs [Pierce, 2013]).

To be more specific, past scholars of scientific public debate have proposed that scientists (both future and current) need to be trained in becoming more proficient with being aware of how they present themselves (e.g. trustworthy, credible, etc.), having control over the language they use (e.g. effective use of emotion, a tone that is not too aggressive, vocabulary that is understandable, etc.), and being able to spontaneously create/improvise messages and arguments that can address the other side of the debate as well as the audience (König & Jucks, 2019; Remillard, 2016). Science communication trainers in other programs have also spotlighted skills such as being aware of the limits of scientific knowledge, knowing the audience (and the social context that whatever is being discussed is situated in), being able to respectfully interact with the audience, knowing how to tell a story, and being adept at non-verbal/physical communication (Besley et al., 2016; Bray et al., 2012).

However, in light of the existing literature having identified rhetorical/communicative skills that training programs should touch upon, another question arises: How can these skills be taught? In other words, what are the best practices that instructors can employ in order to nurture in their students a competency in public science communication? Such a purpose has driven the creation of publications such as (1) Mercer-Mapstone and Kuchel (2015) — who established a framework of core public communication skills (as informed by surveys of experts from the fields of communication, science, science communication, and education) that undergraduate training programs could be based on — (2) Baram-Tsabari and Lewenstein (2017) — who developed a set of learning goals (informed by a review of current communication literature) that any communication training program could adopt— and (3) Kuchel (2019) — who compiled a guide for instructors seeking to design their own science communication training program.

Accordingly, the overarching purpose for this study was to contribute to such efforts in identifying the best practices for training public science communication. To fulfil this purpose, this study was guided by the objective of exploring the students' perspectives on the in-class debates, which in turn was completed by analyzing open-ended surveys in which the students had reflected on their experience. By studying what students felt, insight was gained on what aspects of the activity should be improved (i.e. because the students reported struggling with the aspect or having their learning be hindered by it) and what worked for them (i.e. the students credited the aspect with enhancing their learning) for future renditions of the in-class debates. Student reflections also helped determine whether in-class debates should be used as a vehicle for science communication training in the first place. After all, if the students generally reported learning nothing from the activity, what would be the point of conducting future in-class debates?

The analysis of student perspectives was further guided by the following main research question:

(1) "What common themes arose from student reflections/self-assessments written after their completion of a in-class debate activity?

Two components of the learning experience were further targeted in the following questions:

(2) What aspects of the activity were students able to find success with?
(3) What aspects of the activity did students struggle with?

Before proceeding further in discussing this study and what the examined students experienced, I will provide further background on the pre-existing literature that it is based on, chronicling their examinations of the deficit and dialogical models and how such concepts have been incorporated into past public science outreach programs and science communication training opportunities.

Literature Review

Why Should Science Be Communicated to the Public?

At its most basic level, public science communication's goal is to provide scientific information to the general public — in essence, audiences who are non-specialists in the discipline to which the science being discussed belongs (Trench, 2012). Yet, if this was the whole picture, there would be no need to expand beyond the information-dumping nature of the deficit model and adapt existing public communication methodologies/paradigms into newer lines of thinking such as the dialogical model. As this is not the case, there must be other goals, methodologies, and paradigms guiding the discipline of public science communication.

However, at the time of their publication, Besley et al. (2015) observed how there were no peer-reviewed literature that had looked into this question. In light of this, they propose a set of five goals for effective public science communication: (1) making your message understandable to audiences, (2) ensuring that audiences view scientists as trustworthy and credible, (3) ensuring that audiences view scientists as a group that wants to listen to their concerns, (4) ensuring that audiences view scientists as caring and concerned, and (5) framing or shaping messages so that they resonate with audiences' values or predispositions.

Scientists participating in a "Meet the Scientist" program studied by Woods-Townsend et al. (2016) appeared to be following such goals. In this program, they had presented their work to secondary students, engaging in informal conversations about the research, any other aspect of science (e.g. What is the research process?), or even the scientist themselves (e.g. Why did they choose their academic field?). Throughout these interactions, the authors noticed that the scientists incorporated the first and fifth component of Besley et al.'s (2015) goals by making links between their research to the students' experiences, while also inviting participation from the audience to ensure that the topics being discussed were interesting and understandable. Students also reported that the informal conversations were able to break down barriers, making the scientists seem approachable; passionate about their work; and respectful of their audience's questions, interests, and concerns (fulfilling Besley et al.'s [2015] third and fourth goals).

Promote Careers in Science

Woods-Townsend et al.'s (2016) retrospective interviews with the scientists reveal even more goals, the first of which was to show students that scientists were normal people (i.e. not "boring nerds"), hoping that their audience would subsequently be compelled to consider careers in science. Post-program surveys with students confirm that the scientists were able to dispel such stereotypes, although there was no survey question concerning whether they would consider a career in science in light of this. Regardless, the goal of promoting science careers was reiterated four years later, being one of the motivations behind the Present Your Ph.D. Thesis to a 12-Year-Old workshop. In this program, graduate researchers discussed their Ph.D. thesis with secondary school students, working with them to develop a presentation about it to other students (Kompella et al., 2020). Comparisons between the results of pre- and post-program surveys show students having an increase in positive attitudes towards scientists (e.g. "scientists are cool") and intentions to have a science career, suggesting that its goal of promotion was fulfilled.

Literature concerning such a goal shows up even earlier. Mizumachi et al. (2011) relay the perspectives of scientists participating in a Japanese science café program where they would hold informal conversations about their research with members of the public in a relaxed, café environment. Interviews found that some scientists had wished for younger people to attend their program, taking it as an opportunity to promote science careers to potential future scientists. Coincidentally, this criticism was addressed a year later. A science café was also established in America, explicitly targeting a high schooler audience and incorporating hands-on activities to interest them into joining the field of science (Mayhew and Hall, 2012).

Receive Professional Benefits

The goals of public science communication are not limited to just furthering the field. Communicators may also aim to benefit their organizations/groups. For example, Salmon and Roop (2019) interviewed scientists who had participated in an Antarctic expedition with members of the public in order to raise awareness about and communicate the science surrounding conservation issues affecting the continent. However, the interviewees expressed that they had instead wanted to use the expedition to convince public expedition members to donate to their Antarctic research. Likewise, Roger and Klistorner (2016) touch on how BioBlitzes — events during which conservation organizations collaborate with one another and with members of the public to identify as many species as possible in an area — were opportunities for participating organizations to advertise themselves and obtain more donations. Additionally, they could network with one another and more established entities (e.g. National Geographic), opening the door for future collaborations.

Benefits can also occur on a more personal level. Scientists at the Present Your Ph.D. Thesis to a 12-Year-Old, American science café, BioBlitz, and Meet the Scientist programs described a common goal in joining the program: practicing communication skills (Kompella et al., 2020; Mayhew & Hall, 2012; Roger & Klistorner, 2016; Woods-Townsend et al., 2016). Based on audience reactions, they were able to determine which aspects of their research to focus on in order to demonstrate how interesting their work was and subsequently better engage future audiences. This is an important skill to learn as some of these audiences may include decision-makers and funding bodies — entities that scientists will need to convince to enact science-related policies and to provide more money for their work respectively.

Build Scientific Literacy

Sharon and Baram-Tsabari (2020) highlight another goal of public science communicators: increasing their audience's science literacy — their ability to make science-related choices (e.g. voting for the government to enact policies to mitigate climate change). Accordingly, these decisions will be based on two factors: one's understanding of what science entails and one's ability to critically evaluate and use information obtained from sources of scientific expertise.

Addressing the former factor was one goal that BioBlitzes can fulfil. Roger and Klistorner's (2016) survey found that public participants reported having a better understanding of how scientists collect ecological data and use it to better understand the local environment. However, members of the public cannot always accompany researchers into the field.

Hence, increasing their audiences' understanding of science was an additional goal for those organizing the aforementioned science cafés and student interactions with scientists (Kompella et al., 2020; Mayhew & Hall, 2012; Mizumachi et al., 2011; Roger & Klistorner, 2016; Woods-Townsend et al., 2016). While the audience may not be able to directly participate in the scientific process, they can ask whatever questions they would like to presenters (e.g. aspects of how the scientific process works to solve problems, how the scientists' research is relevant to the audience). Pre- and post-program surveys for student participants in the Present Your Ph.D. Thesis to a 12-Year-Old workshop show an increase in respondents reporting that they understand science (Kompella et al., 2020), suggesting that these student-scientist interactions can fulfil this goal. Still, it should be noted that this increase may have also resulted from students being required to create their own presentations about the scientists' theses.

While the scientists may be providing their audience with knowledge about their fields, other people may not have access to such accurate information. Returning to Sharon and Baram-Tsabari (2020), they spotlight the efforts of two online Facebook groups that address this — one where people can directly ask questions about vaccination to medical researchers and practitioners and another where they can ask about nutrition to dietitians. Interviews with the experts reveal that a common goal for them was to counter misinformation that their audience may have encountered. Some also highlighted a related goal of teaching people how to critically evaluate any information they read as well as the credibility of the sources they get such information from.

In light of this recommendation, the experts discussed how another of their goals was to establish themselves as competent and reliable, reflecting the goal of demonstrating credibility described by Besley et al. (2015). To achieve this, they would emphasize their credentials, rely on pre-existing literature to support their answers, and never speak beyond their knowledge. Experts would also craft posts in accordance with the participants' needs and respect their independence in making their own decisions in light of what information is given to them. Such respect ties into the experts' third goal of establishing themselves as benevolent and empathetic people (calling back to Besley et al.'s [2015] goal of showing care/concern).

Get Your Audience to Have Fun

In some cases, public science communication goals might not be even related to science. For example, Salmon and Roop (2019) refer back to an Antarctica-themed festival with a science-themed component (e.g. science cafés, panel discussions with researchers) where the coordinators' mainly wanted members of the public to just have fun. While this goal can stand on its own and does not require any justification, such entertaining educational endeavours (or "edutainment" as it is sometimes called; Addis, 2005) can impress learning outcomes onto those who experience them, whether via museums (Balloffet et al., 2014), television shows (De Backer

& Hudders, 2016), video games (Green & McNeese, 2007), or interactive theatre shows (Ritterfeld et al., 2004) amongst other media.

However, the four cited publications point to how learning outcomes may not be long-term, may not occur in all audiences, and/or may accidentally be side-lined in favour of the entertainment nature of edutainment. Still, the authors all recommend continuing forth with using their respective medium of interest in edutainment efforts. Ritterfeld et al. (2004) in particular declare that “enjoyment is the most important predictor for learning (p. 24),” having based this conclusion on the results of quantitative surveys that they had administered to children attending an “edutaining” interactive theatre show. To be more specific, they had found that children who reported having had fun during the show tended to score themselves as having experienced higher levels of learning relative to children who had not enjoyed the show.

Such results are in line with Purinton and Burke (2019), who showcase a learning activity designed by instructors of an accounting course to be fun. In the activity, students played a round of the board game Monopoly®, during which they were also required to apply/practice various concepts taught by the course (e.g. recording in-game transactions into a ledger, calculating income and tax expenses). A subsequent exam covering these concepts saw the Monopoly®-playing students score higher on average compared to students who had learned the same material but had not experienced the activity.

As an additional observation, Purinton and Burke (2019) note that the students described playing the game as something that had increased their learning engagement (i.e. their inclination to invest their time and energy into learning; Kuh, 2001). As Tews et al. (2015) summarize in their literature review, past publications highlight the importance of such student engagement as a factor that can facilitate improved academic performances (e.g. Carini et al., 2006; Kuh et al., 2008). Continuing on, Tews et al. (2015) discuss how their own surveys of undergraduate students reveal that respondents who evaluate a course as being fun also tend to report being engaged with it, thus spotlighting fun as a driver of student engagement and, by extension, a factor associated with enhanced learning.

Returning to the realm of science, the results of Lin et al. (2012) are in line with both Purinton and Burke (2019) as well as Tews et al. (2015). Lin et al. (2012) had found in their study that secondary school students who self-reported high levels of fun or engagement in learning science achieved higher scores on-average in a standardized assessment of scientific literacy compared to students who experienced lower levels of fun or engagement.

Further demonstrating the importance of making science education fun and engaging, Lin et al. (2012) also observed that higher perceived levels of these two characteristics correlated with students holding stronger intentions to participate in future scientific endeavours. Exemplifying such a result, Raddick et al. (2010) point to how fun had been one of the major motivations driving members of the public to get involved with a citizen science project wherein they would assist astronomers with classifying galaxies. Accordingly, Lin et al. (2012) advocate for incorporating fun and engagement into the design of educational experiences — both formal and informal (i.e. directed to public audiences).

Fulfil a Social Contract

In light of all of these goals, one question still remains: why should scientists care about fulfilling them in the first place? Carr et al. (2017) surveyed chemists on their perspectives on why science should be communicated to the public, finding that many agreed that scientists had a responsibility to do so. While no further explanation for why respondents felt this could be found due to the survey's closed structure, Esmene et al. (2017) provide some more detail. Interviewing those who researched electric vehicles, all of their respondents — like with Carr et al. (2017) — expressed that they were responsible for making their work accessible to the public. One respondent, building on this, mentioned how this thinking stemmed from the fact that members of the public may be indirectly funding their work via taxes that feed into research grants from the government. In a sense, the public is paying for a product and should thus be entitled to receive information about it.

How Can Science Be Communicated to the Public?

Shifting Away from the Deficit Model

Regardless of whatever goals the scientists in the programs described in the previous section may hold, what they all have in common is that they are organizing two-way dialogues — sometimes even inviting participation into their work (Roger & Klistorner, 2016) — as opposed to just presenting information in a one-way manner. As such, there appears to be some movement away from the deficit model and into the dialogical model.

This movement is further illustrated by Nadkarni et al. (2019) — whose publication was titled “Beyond the Deficit Model” — a study of a communication program where scientists adopted the role of science ambassadors. In it, program organizers explicitly requested that ambassadors focus on audience-oriented goals (i.e. show that they share the same values as their audience, respect their audience’s identities, are concerned with their audience’s well-being and opinions, are interested in learning from the audience, and are not completely disconnected from the public) as opposed to being concerned with discussing as much information as possible. Surveys of those who had been spoken to by the ambassadors indicate that they had succeeded in their goals.

Such results, combined with similar positive evaluations from students in the Meet the Scientist and Present Your Ph.D. Thesis to a 12-Year-Old programs (Kompella et al., 2020; Woods-Townsend et al., 2016), suggest that the dialogical model can be useful for science communicators in establishing fruitful dialogue, although it should be noted that my literature search did not find any study directly comparing the two models’ respective efficacies (e.g. Are there certain topics/contexts where an audience will be more engaged by communicators using one model over the other?).

Being Constrained to the Deficit Model

It should also be noted that regardless of what the literature suggests, some scientists may still be unable to adopt a dialogical approach to their public communication efforts. For example, the scientists interviewed by Mizumachi et al. (2011) had negative opinions on taking part in the science café events and were reluctant to participate in future editions. Such a dislike stemmed from how they were concerned that they were unequipped to be science communicators due to lack of training.

This outlook ties into behavioural models that have identified one’s own beliefs into whether they can adequately perform a behaviour (i.e. termed as “self-efficacy”; De Vries et al., 1988) as a determinant for whether one actually performs (or intends to perform) said behaviour (e.g. Kollmuss & Agyeman, 2002). Past research from science communication scholars Drs. John C. Besley and Anthony Dudo (as well as their associates) foreground one of these models in particular — Ajzen's (1991) Theory of Planned Behaviour (Besley et al., 2015; Besley et al., 2018a; Besley et al., 2018b; Besley et al., 2019; Dudo & Besley, 2016).

In the context of public science communication, this theory identifies the following as determinants for whether a scientist is willing to make the effort to engage the public: (1) self-efficacy (Besley et al., 2018a; Besley et al., 2018b), (2) attitudes towards potential audiences or the act of engagement itself (e.g. Do scientists believe that their attempts to make their content seem appealing to audiences are misleading/unethical? Do scientists like communicating in the first place?), (3) normative beliefs (i.e. Do scientists believe that their colleagues are also trying to engage the public? Do scientists believe that their colleagues would support other scientists trying to engage the public?), and (4) response efficacy (i.e. Do scientists believe that they will experience any benefits from engaging?).

As Besley et al. (2019) add, the four factors can also influence whether a science communicator chooses to utilize a certain rhetorical/communication strategy (e.g. storytelling, active listening, attacking the credibility of their opponents) or not. However, it should be noted that the evidence for whether each factor's respective influence can consistently impact a scientists' behavioural intentions to undertake public engagement efforts is mixed (Akin et al., 2021; Besley et al., 2019; Dudo & Besley, 2016). Regardless, extant publications (e.g. Besley et al., 2019; Dudo & Besley, 2016; Trench & Miller, 2012; Yuan et al., 2017) still highlight science communication training as a potential avenue for making one's attitudes, beliefs, and sense of efficacies more conducive to starting public engagement.

How Can Scientists Be Trained to Communicate to the Public?

However, returning to Esmene et al. (2017), Grubert and Cook (2017), and Salmon and Roop (2019), most of the researchers they surveyed/interviewed (from the fields of electric vehicle research, the oil and gas industry, and polar science respectively) stated how they had little to no formal training experience in public science communication. This trend also appears in surveys/interviews given to those working in ocean science (Altman et al., 2020), environmental health (Appiah et al., 2020), and ecology (Hansen et al., 2018). In light of this deficiency, these studies call for the creation of training opportunities that can teach scientists public communication skills. My literature search was able to find eight publications evaluating seven of such opportunities.

The smallest of these was a single 90-minute workshop situated in an undergraduate laboratory course at Rice University (Beason-Abmayr & Wilson, 2018). In this workshop, the course instructor invited the director of the university's communication center (which provides peer tutors for students seeking help on written assignments) to discuss how research results can be orally delivered (e.g. choosing what to discuss, designing accompanying presentations).

The Art of Science Communication — a set of six workshops hosted by the American Society for Biochemistry and Molecular Biology (Greer et al., 2018) — and the Engage program — a 10-week graduate-level course at the University of Washington (Clarkson et al., 2018) — discussed similar skills, but both added components where students perform their own final public presentations.

The Decoding Science program — a set of four workshops held at the University of Missouri — takes a deeper dive into communication, touching upon the underlying theories behind the visual design of presentations, the psychology of engaging an audience, and the framing of a narrative (Luisi et al., 2019; Rodgers et al., 2018).

Meanwhile, programs at Stony Brook University's Alan Alda Center for Communicating Science concern themselves with other aspects of oral delivery, namely the ability to improvise and spontaneously adapt the messages being presented based on the reactions (i.e. body language) of the audience (O'Connell et al., 2020).

Moving away from oral media entirely, McCartney et al. (2018) describes a graduate-level course at the University of Wisconsin-Madison's Center for the Integration of Research, Teaching, and Learning consisting of six 75-minute sessions where students learn how to annotate scientific literature in a way that would be accessible for readers.

The last of the training opportunities is ComSciCon-Triangle — a two-day program full of workshops where attendees receive hands-on training from and attend panel sessions with invited communication experts (e.g. academics, science journalists, film-makers) to improve both written and oral presentation skills (O'Keeffe & Bain, 2018).

Why Should Science Communication Training Programs Be Assessed?

As noted by publications such as Clarkson et al. (2018), these evaluations can be useful for justifying investment into training programs. Universities may not wish to fund programs that are ineffective at teaching skills, nor would research supervisors be convinced to encourage their students to take time away from their work to attend such activities if this were the case.

Additionally, the evaluations' descriptions of the training opportunities may provide guidance to professors who wish to incorporate such activities into their science courses and to ensure that their students come away with the skills to communicate whatever is taught to the general public. Such guidance is especially needed given how science communication scholars such as Bankston and McDowell (2018), Brownell et al. (2013), and Schiele and Landry (2012) regard the current state of science communication training opportunities to be underdeveloped — a consequence of how the field of science communication is itself in its infancy and still drastically progressing in terms of factors like research output, support by other scientists or governments, and jobs available (Gascoigne & Metcalfe, 2017; Guenther & Joubert, 2017; Riedlinger et al. 2019).

To build on this, Kuchel (2019) draws attention to how there has been growing academic interest surrounding science communication training. In particular, publications such as Bennett et al. (2019) and Brownell et al. (2013) have called for more research into the "best practices" for science communication training. After all, with how vital such opportunities/programs are in ensuring that scientists are competent enough to discuss science with the public, it seems inappropriate for them to still be under-researched and for their instructors to be left with little guidance on how to design such training. As such, Bennett et al. (2019) identifies program evaluations such as the ones cited in the previous sections of this literature review as an avenue for remediating such an issue.

With that being said, the cited evaluations do have some caveats. To start with, their authors were seeking to measure a pre-established set of quantitative factors (e.g. pre- and post-program rubric scores pertaining to their ability to give an engaging presentation) in order to judge the merits of their programs. As Luisi et al. (2019) highlights, holistic assessments that look at students' personal learning outcomes can also be useful. To be more specific, rather than being just a final grade for a program, holistic assessments would call attention to possible points that (as suggested by the students themselves) could improve the training process by better aiding students in fulfilling their learning goals. After all, not all learning outcomes may necessarily translate to evaluating a program's ability to improve public science communication skills (e.g. students indicating that they found the experience enjoyable may not be the most engaging communicators), but they can still hold valuable insights (e.g. trainers may want to know if students are enjoying the program).

Why Should Science Communication Training Programs Focus on Rhetoric?

Another caveat pertains to how the programs all (based on their descriptions) assume that communicators will always be facing friendly audiences in controlled environments where everything goes according to their plans as everybody will trust them. As Gross (1994) posits, this is problematic as it would still fall under the deficit model of communication. After all, communicators may find themselves talking to those that disagree with them on scientific topics and needing to figure out how to retort against such parties in contexts such as town hall forums or public debates.

To be more specific, Gross (1994) had touched upon rhetoric, a concept in communication defined by rhetorician Kenneth Burke as the usage of words by one party that can "form attitudes" or "induce actions" in — or in other words, persuade — their audience. As Gross (1994) further elaborates, such persuasion is based on the tenet of trust. In essence, a communicator will only have successfully persuaded someone once they have gained the trust of said person.

Correspondingly, Gross (1994) takes issue with the deficit model as its one-way nature and characterization of audiences as passive are based on the assumption that scientists will always be trusted. Thereby, no attempts at persuasion/rhetoric need to be made beyond figuring out how to simplify scientific information in a way that can be easily transferred to and easily understood by the audience.

As Gross (1994) pushes, rhetorical strategies should be more than this; science communicators should go into their interactions with audiences with the understanding that they need to build trust and work with whoever they are speaking with as opposed to arrogantly dismissing the public and believing that its members will always yield to the more-educated scientists. After all, Gross (1994) points to the fact that one of the contributing factors towards

Wynne’s (1992) sheep hill farmers’ distrust of scientists was how the latter group had dismissed the former’s knowledge.

Likewise, Ceccarelli (2011) warns science communicators about how they cannot simply approach debates against misinformation-peddling parties by simply dismissing them. Such a flippant move will only serve to validate the communicators’ opponents in the eyes of any observing third-party. After all, if the scientists were confident in being correct, why would they be seemingly afraid of debating those who oppose them?

Even if science communicators choose to engage in debate, there are additional dangers. More specifically, Ceccarelli (2011) caution that the communicators may fall into “argumentative traps” laid out by their opponents — for example, appealing to the concept of “freedom of expression” as a way to justify their dissemination of misinformation and vilifying attempts to shut them down — thereby losing the debate as well as credibility with third-party onlookers.

In response, Ceccarelli (2011) advocate for educational efforts that can develop in scientists/budding science communicators knowledge of and competency in harnessing rhetorical strategies. Doing so would facilitate them in navigating around the arguments of any spreader of misinformation, thereby successfully defending the validity of and promoting science. Such a recommendation is echoed by Druschke and McGreavy (2016) in the context of promoting ecological conservation efforts as well as by Ihlen (2020) in the context of combatting vaccine hesitancy.

Summarizing Past Literature // Contribution to the Field of Education

The results of my literature search highlight that science communicators hold various goals in their work that extend beyond simply giving their audience information. To fulfil these goals, they are harnessing a two-way model where they are mindful of their audiences (e.g. What topics would interest them? What topics are relevant to their lives?). However, some scientists may feel that they lack the knowledge or skills to do this. They may also hold attitudes and beliefs that sway them against wanting to engage with the public. As such, current literature recommends a remedy in the form of science communication training.

However, there is a problem — a majority of the scientists surveyed/interviewed by the literature cited above stated that they had little to no science communication training. In light of this, programs — seven of which were described by the results of my literature search — have been established to help attendees practice their oral and written delivery skills. Yet, no information was given on whether they would also be trained on how to harness rhetorical techniques as a pathway towards engaging with those who may disagree with them, especially as such parties may themselves employ rhetorical strategies to counter and reduce the credibility of scientists that are unable to adequately retort — either through the scientists deliberately refusing to engage with them or being ignorant of rhetoric-informed ways to respond back.

Addressing this need, there is a science communication course at an Ontarian university with an activity where students are involved in a series of in-class debates about various controversial science-related topics (e.g. Flat Earth Theory) as both participants and third-party audience members. However, no investigations have been performed to examine what past students have felt when experiencing the activity.

Accordingly, there is a space for further exploration to determine what students feel can be improved or is useful on their journey to become engaging science communicators to the public. Additionally, given the general dearth of pre-existing literature looking into the usage of in-class debates in science communication training, the study also serves as an preliminary exploration that uncovered and identified avenues of research that future science communication scholars can take to build a more comprehensive understanding of the ability (or lack thereof) of in-class debate activities in training prospective science communicators — for example, by quantifying the post-debate improvements/regression in specific skills named by this study or by identifying factors (e.g. demographic) that could have caused the variance amongst the survey results of this study's students.

Theoretical Framework

Regardless of future steps, the current research that I am conducting will be steeped in the theoretical framework of Kolb's (1984) Experiential Learning Theory (ELT). ELT suggests that the act of creating knowledge comes about from one's own processing of their experiences. This process is continuous, iterative, holistic (i.e. aware of outside connections between the wider context and the learner themself), and cyclical, progressing from "Concrete Experiences" (e.g. their experience of performing a task) to "Reflective Observations [about the experience]" , "Abstract Conceptualization" (i.e. creating a theoretical schema to explain what happened), and

“Active Experimentation” (i.e. applying the schema to a new situation) (Abdulwahed & Nagy, 2009; Kolb, 1984; Konak et al., 2014). At its core, Kolb’s ELT encourages educators to focus on students’ personal experiences over the course of their learning as opposed to simply evaluating their ability to recall and manipulate facts and formulae about a subject (Kolb, 1984), reflecting other literature that endorses hands-on activities/experiences over passive, lecture-based modes of learning (e.g. Abd-El-Khalick, 2002; Dilger & McKeith, 2015).

Starting with their own usage of ELT when conducting interactive computer science activities for students, the literature review of Konak et al. (2014) observes that Kolb’s ELT has been applied to guide program design in the fields of chemical engineering (and technical/vocational disciplines in general) and social work (Abdulwahed & Nagy, 2009; Clark et al., 2010; Raschick et al., 1998) as practical experiences (e.g. laboratory work and practicums at community service agencies) are a core component of training. Kolb’s ELT has also been present in the context of science communication training. For example, in their assessment of the University of Missouri’s Decoding Science workshop series, Luisi et al. (2019) explored the post-program reflections of participants to determine whether their learning outcomes were in line with ELT’s principles (e.g. realizing that learning how to communicate was a process that would continue past the end of the workshops).

Another instance of the theory in action is in the Ontarian Science Communication course that this study is investigating; its instructor had drawn directly from it when designing the course’s hands-on activities (A. Brown, personal communication, April 19, 2021). Focusing on the in-class debate activity, one (and a half) possible cycle of a student’s experiential learning could be (1) observe the debates of other students (Concrete Experience); (2) internally reflect on their feelings after seeing the debate performances, forming opinions about what was done (Reflective Observation); (3) create or add on to their mental schema about what they can do when they debate (Abstract Conceptualization); (4) use this schema when they participate in the debate (Active Experimentation), which means they (5) undergo a new experience of debating (Concrete Experience); and (6) internally (and externally via instructor-given surveys) reflect on their feelings after the debate, forming opinions on what they can do in future science communication scenarios (Reflective Observation).

In the context of the course, the cycle pauses in the sixth (i.e. first repeat of the second) stage with the student’s completion of an instructor-given survey that prompts their reflections about the activity (e.g. What could they have done differently when debating and would it change how they felt about the activity?). After all, as Oliveira et al. (2021) remark, students reflecting on and self-assessing their own performance in a communicative activity (in their case, an oral presentation) can allow them to take a step back and develop a clear and critical self-awareness of what they could have said, how they could have said it, and how they would be interpreted by an audience. Subsequently, they would be able to identify areas in which they would need to improve or areas in which they are proficient at.

Beyond the course's completion, the rest of the cycle will continue and constantly loop back when the students participate in future debates. Accordingly, given how I will be analyzing the themes present in the students' reflections on their learning experience, this would mean that this study's methodology is nested in the theoretical framework of Kolb's Experiential Learning Theory.

Methodological Framework

Setting

In this study, I will be examining a third-year science communication course titled "The Public Communication of Science" and designed to prepare science students (with no particular discipline/field specifically being targeted) at a university in Ontario, Canada, for future situations where they will have to communicate scientific information and research to non-specialist audiences. While this 13-week course is primarily taught by a professor with a Ph.D in biology (who also co-supervised this study and has approximately 14 years of university teaching experience), guests such as other professional science research/professors, a professor of theatre, a journalist, a theatre manager, and a brand consultant provided guest lectures. The diversity of such a roster demonstrates how this course had been designed with a multi-disciplinary outlook that sought to merge science with the fields of communication, public speaking, and media relations. Additionally, the course's lectures are designed to teach students about various concepts and skills (e.g. improvisation, being comfortable with body language, being comfortable with speaking to public audiences, being aware of their biases to ensure the fairness/accuracy of what they are discussing, being concise) in common public communication contexts that scientists find themselves in — in particular, introducing one's own scientific work in a single minute, responding to/debunking pseudoscience, writing an opinion piece for a newspaper, being interviewed by news media, pitching science-related business ideas, and writing government briefing reports.

Supplementing the lectures, students are also required to complete assignments that simulate these contexts, allowing them to have a low-stakes environment detached from the real world (although in the case of the newspaper opinion piece, bonus marks were awarded for managing to get one's writing published in an actual print publication) where they can practice and become more comfortable (as opposed to leaving them to deal with their first interview or business pitch without any preparation, idea, or experience on what such experiences would entail).

The culmination of these assignments and all the skills they obtained was the final project: the in-class debate activity. Students were separated into teams of two (or three depending on the class size), and each pair of teams picked a particular topic that they wished to discuss for their debate. For example, the 2019 iteration of this course saw the topics of (1) the validity of Flat Earth Theory, (2) the limitation of current human population (over)growth, (3) the legalization of all drugs in Canada, (4) the relative importance of applied/practical scientific research compared to basic/pure research, (5) the relative healthiness (to humans) of vegan diets compared to omnivory ones, (6) the safety (to humans) of genetically-modified food, and (7) the identification of social media as a cause of mental illness in youth. While students were allowed to choose their topic, they were not allowed to select in advance the stance that they would argue for. Instead, they were expected to work with their debate partners in conducting the necessary research to prepare points, arguments, and narratives for both sides, only finding out on the day of their debate (by way of flipping a hockey puck) which side of the debate they would be on (i.e. "for" or "against" the topic).

During the debate, the "for" team alternated with the "against" team in presenting what they had in three sections: a five-minute opening argument, a five-minute rebuttal, and a two-minute space for concluding remarks. There was no requirement or guidance on exactly what the students needed to present in these sections. For example, they could take the time meant for their concluding remarks and substitute it with one last set of rebuttals against the other side. As such, students were required to be able to independently call upon all of the rhetorical techniques and communication skills that they had learned/practiced in the course (e.g. be concise enough to fit points into the short timeframe of each debate section, tailor what their arguments to fit and better engage the audience, harness their improvisation skills and stay calm enough to come up with rebuttals on-the-spot) to ensure an effective debate performance. Efficacy in this case was represented by their fellow classmates. To be more specific, upon completion of the debate, the classmates voted on which side had "won" the debate, after which they detailed more specific criticisms/compliments for the debaters. This would allow said debaters to have a glimpse on what strategies/communication tactics or general performance aspects worked or did not work in terms of being engaging/impactful.

Once this was all done, there was still one final activity component for students: a self-reflective open-ended survey about their thoughts and feelings on what they experienced during the debate. To obtain a final mark for the activity (as the course instructor would be assessing their responses), students were required to answer the following questions: (1) What did I learn most from doing this activity? (2) How will this communication skill help me progress towards my goal of communicating science more effectively? (3) What was something that surprised me about the research that went into this assignment? (4) What was something that surprised me about the work I put into this assignment? (5) What do you think were the strong aspects of your communication (could be content-related or style-related or both)? (6) What do you think were the weak aspects of your communication (could be content-related or style-related or both)?

As the aforementioned Experiential Learning Theory suggests, such post-experience reflections can facilitate one in developing their own knowledge (Kolb, 1984) — in the case of this activity, knowledge surrounding how to debate science. However, as Oliveira et al. (2021) (a publication with which the course instructor was involved with) found, students' self-perceptions/reflections of their performances may not be entirely accurate. As a result of the emotions that they were experiencing at the time, students may selectively remember portions of their experience (e.g. moments where they were stressed or embarrassed), thereby distorting their memory. Consequently, students may need to re-acquaint themselves with an unbiased view of what actually happened by watching a video recording of what they had done. Hence, the course instructor followed this insight by requiring the students to review a recording of their debate and, in light of what they had seen, answer this additional request of (7) "Name something that surprised you about watching the video of your communication."

Aspects of Training Effectiveness

To reiterate, the main objective of this study is to explore student perspectives on their experience with this in-class debate activity, and to do this it will seek to answer the question of what common themes arose from the post-activity reflections/self-assessments that I have just detailed. To provide a sense of structure and clarity to the results of this study, a framework was required that could be used to organize all of the themes that were identified in the student reflections. While this study is not an evaluation of the in-class debate activity's effectiveness in training the students and is instead an exploration of their thoughts and feelings, this framework can still draw inspiration from previous literature that does fulfil an evaluative role. In order to do this, another question must first be answered: What would they consider as effectiveness in the first place?

Looking back at previous literature assessing other science communication training programs, researchers can focus on whether participants increase their knowledge of public communication concepts and skills — e.g. choosing content to discuss, designing presentation graphics, delivering oral presentations, and answering questions (Beason-Abmayr and Wilson, 2018) — over the course of their study. However, researchers examining the Engage, Alan Alda Center for Communicating Science, ComSciCon-Triangle, and Decoding Science programs expanded beyond this by checking if participants experienced changes in non-cognitive aspects (i.e. those related to one's own personality and temperament) (Clarkson et al., 2018; O'Connell et al., 2020; O'Keeffe & Bain, 2018; Rodgers et al., 2018). For example, an increase in perceived self-efficacy was a common indicator of effective training.

Putting all of these measures together, Rodgers et al. (2020) created an instrument for assessing the effectiveness of science communication training programs. This instrument is a set of Likert scales that revolve around five different psychological constructs in science communication trainees. Paraphrased, the constructs are the trainees' (1) perceived self-efficacy in communicating science, (2) motivation to learn for the sake of learning (as opposed to external factors such as higher grades or money), (3) attitudes and feelings (positive, negative, or neutral) that they hold towards the training experience, (4) communication behaviour (i.e. During the program, did they use the skills they were taught? Do they intend to use what they learned in future communication contexts?), and (5) knowledge (i.e. Did they learn more about how to communicate science?).

Additionally, Rodgers et al. (2020) emphasized that their instrument had already been reviewed and endorsed by their academic peers in terms of its face validity (in this case, its ability to quantify effectiveness) and content validity (i.e. each construct was comprehensively described by their respective sets of Likert scales). Furthermore, their study also demonstrated that it was able to reliably detect changes in the constructs by finding differences between the scores of the Likert scales in surveys administered to trainees before and after they undertook the Decoding Science program. As their evidence suggests that their instrument is robust, I will be using their constructs as a starting point for possible themes that students may refer to when reflecting on their experiences debating and watching others debate.

Data Collection

As previously detailed, this study analyzed the self-reflective surveys that students were required to complete after the in-class debate activity. Therefore, this study intrinsically incorporated a survey design. In addition to reflecting the general methodology of Rodgers et al.

(2020), this design follows Creswell (2012), who had recommended the usage of surveys for assessing educational programs and identifying general trends in a sample (which, in this context, refers to the themes present in student reflections).

With this course having been conducted for multiple years, there were several sets of surveys available for analysis. However, this study only looks at one to fit time constraints. This set comprised 28 undergraduate students who had completed the debate activity and submitted survey responses to the course instructor. Students were not required to provide any other personal information for research purposes (e.g. age, gender identity, cultural identity) to preserve their anonymity. After all, this study is an exploratory one. There is no need to collect such information as I am not seeking to identify or quantify the relationship between the themes observed in the students' survey responses and any possible determinants (e.g. gender differences in how students experienced a certain aspect of the activity). Furthermore, I am mainly concerned with ascertaining what the themes would potentially be in the first place.

However, given that the survey was an in-course activity that would contribute to each students' overall course grade, their full names had been submitted along with their responses. With that being said, this information was only available to the course instructor; I — the primary investigator — did not have any access to it.

To supplement the collected survey data, this study also looked at audio-visual recordings (i.e. videos that the course instructor took) of the 28 students' debate performances. As another measure for preserving anonymity, the course instructor had blurred out all faces in these videos before allowing any further analysis on them. Thus, all students in their respective survey responses and video footage were identified only by a number (e.g. "Student 28"), with only the course instructor having knowledge of their true names.

Data Analysis

While the course's enrolment may not have been high (relative to lower-level courses that have class sizes in the hundreds), it is comparable to the sample sizes of past assessments of training programs such as Clarkson et al. (2018), O'Connell et al. (2020), and Rodgers et al. (2018). Furthermore, a benefit to having fewer students was that it opened up the possibility of using qualitative, open-ended survey questions. Collecting responses from more students would have forced the usage of quantitative, close-ended ones (e.g. the Likert scales of Rodgers et al.

[2020]) as time constraints would preclude the feasibility of conducting the time-consuming coding analysis associated with open-ended approaches (Creswell, 2012). As Creswell (2012) noted, open-ended survey questions are ideal for contexts where researchers wish to explore other possible responses that could extend beyond their preconceptions. Given how Rodgers et al. (2020) conceded that their instrument may not be able to represent all aspects of effectiveness, the open-ended surveys allowed for the students to present responses that may fall outside of the instrument's boundaries. Accordingly, the open-ended nature of these surveys meant that none of the Likert scales of Rodgers et al. (2020) were used, nor were their identified aspects of effectiveness explicitly referred to in the questions. Given how the instrument had been informed by past literature describing the perspectives of real students, I had expected a portion of these aspects to organically come about in the reflections anyway.

Regardless, I conducted a thematic analysis, iteratively reading all survey responses to identify codes within and to subsequently categorize them in accordance to the themes/constructs of Rodgers et al. (2020) and/or entirely new ones that fall outside. Such an approach was in line with Xu and Zammit's (2020) hybrid methodology that combines deductive (i.e. based on a pre-existing framework) and inductive (i.e. based on the data itself) coding.

Once all responses were coded, their relative frequencies to one another were counted for two reasons: (1) to provide a short summary of the themes and (2) to provide a reference for what themes instructors organizing future iterations of the debate activity should prioritize (e.g. if a theme was barely discussed or if many students indicated they struggled with a certain theme, instructors may wish to divert extra in-class attention via more in-class activities or other forms of support to such themes).

Triangulation - Video Data

However, one limitation of using self-assessments is that they may not present the whole picture. For example, Clarkson et al. (2018) evaluated the Engage program by having its participants rate their change in science communication competency after revisiting footage captured of the first and final presentations they performed over the course of training. External reviewers were also recruited to watch these presentations and provide their own neutral evaluation of the participants' change in competency. Accordingly, the authors found discrepancies between the ratings of the two groups — the external reviewers described a much greater improvement in the participants' science communication competency than the participants themselves. From this, they recommended that future researchers do not rely only on self-assessments.

In the case of this study, the video recordings of students' performance can also be analyzed for triangulation purposes (i.e. using multiple data sources to see if they corroborate one another and to provide further detail on the phenomenon being studied; Creswell, 2012). As such, for this study to be truly comprehensive, I would have transcribed the video data (including any other visual observations such as body language) and conducted another thematic analysis to code it in accordance with the constructs of Rodgers et al. (2020) and beyond. However, given the amount of video data that was collected, iteratively watching and analyzing all recorded footage to corroborate surveys was not feasible due to (1) time constraints, (2) how subjective some possible themes would be (e.g. someone may describe themself as having performed well, but what does "well" even entail?), and (3) how students' feelings may not be visible (e.g. someone may describe being nervous but not appear to be physically expressing such emotions due to wanting to seem confident and professional to the audience). Consequently, a filter was required to cut down on the amount of effort dedicated to analyzing the video recordings.

To create this filter, I returned to the qualitative survey data, specifically looking for students who had provided responses that (1) were generally more in-depth and detailed relative to the other responses, (2) discussed events (i.e. what the students said, how the students physically behaved) that could be objectively observed or heard in the video recordings, and (3) demonstrated themes commonly mentioned by all respondents. This search came up with three students. Afterwards, I watched in-debate video recordings of the three students of interest, making a point in particular to look for and identify the appearance of any themes that had arisen in the quantitative thematic coding of the students' survey data. Such observations could corroborate what the three students had submitted for their reflections. Alternatively, the video recordings could have refuted them. Regardless of outcome, I performed this qualitative thematic analysis of the video data to provide more context for what the three students of interest had written.

Overall Design

Putting it all together, there were two main components to this study. The first was a qualitative thematic analysis of survey data, with the results also being transformed into a quantitative format by way of a frequency count for the themes that were uncovered. The second was a qualitative analysis of a subset of the video data that was informed by the results of the first component (i.e. the subset was delineated based on the themes that arose from the analysis of the survey data). Given that the results of both components were combined in order to provide a fuller picture of student experiences in in-class debates, the overall structure can be categorized as a mixed-methods convergent design (Creswell, 2012).

In the next section of this report, I will be relaying the results of the analyses associated with student reflections/surveys in addition to some of their implications. Afterwards, I will use observations of what transpired in the video recordings of three students' performances as a platform for further discussion on what respondents reported experiencing during this debate activity.

Results and Discussion

Students' Survey Responses

While all categories that arose in the students' reflections/self-assessment of their performance in the in-class debate activity could be organized into the five constructs of Rodgers et al. (2020), this is not to say that it was a perfect match. The scales corresponding to the constructs had each demarcated their own sub-themes, and the scope of some of them did not exactly fit what this study's students had written. In particular, the construct referring to science communication trainees' knowledge had simply been a general numerical scale for users to self-quantify their knowledge on how to communicate science. Meanwhile, this study was able to identify each of the science communication principles/rhetorical strategies that the debating students had drawn upon for their respective performances, subsequently identifying the number of respondents that indicated learning more or being surprised about a new aspect of the principle, finding success with it, or struggling with it.

On the other hand, not all of Rodgers et al.'s (2020) sub-themes were present in this study's survey data. For instance, this study could not glean any reference to the sub-theme of "Positive Outcome Expectations" (associated with the construct about science communication trainees' attitudes and feelings towards their training experience) in the 28 students. These discrepancies are to be expected. After all, this study explicitly did not rely solely on deductive coding — rather, a hybrid approach (as described by Xu and Zammit [2020]) combining deductive and inductive coding. Thereby, readers of this paper should only consider the following reporting of the themes found in this study's survey data as an adaptation of Rodgers et al. (2020) rather than a faithful adherence. The lack of titles matching those of their five constructs says as much.

Regardless of any adherence/discrepancies, the results of the students' survey responses indicate the presence of three overarching themes between the five constructs. The first theme expands on the construct pertaining to the students' attitudes and feelings that they hold towards the activity by merging it with the constructs about the students' motivation to learn/participate in the activity, their perceived self-efficacy in communicating and/or debating science, and their communication behaviour during and after the activity. After all, all four constructs are generally about the effect the activity (via factors such as its structure, its tasks, or its associated learning environment) had on the students' attitudes and feelings.

The second and third themes are both about the construct pertaining to the students' knowledge about public communication — in essence, whether the students had obtained more knowledge about or struggled with general (for the former) or debate-specific (for the latter) public communication principles/rhetorical strategies. Regardless of which theme they were organized into, a list of these principles/strategies is available in **Table 5**.

The Activity's Effect on the Students' Attitudes and Feelings

In total, half of the 28 respondents reported holding positive views towards the activity (**Table 1**), with some of them employing descriptors such as "fun", "cool", and "fantastic" to characterize the overall learning experience that they had had. A subset of respondents had drawn particular attention to how they were required to prepare for both sides of a science-related issue in this activity, with some of them having enjoyed researching and acting as a supporting member of the other side (e.g. because of how amusing some arguments — such as Flat Earth Theory supporters maintaining that there is an ice wall surrounding all "edges" of the Earth — were to them).

"Even in the heat of the debate I was having a ton of fun and it was hard to not smile and laugh at every point the opposition made [...] *When debating a side that has less merit, I knew I would have to 'act' a little and get into character. I think that I was surprised with how into it I was — although I really liked it!"* [Student 14]

Such positivity came in spite of how most respondents (specifically 18) wrote about being surprised at how certain aspects of the debate activity were more difficult than they expected (**Table 1**). The most commonly-discussed source of such difficulty was the amount of time that students needed to research, create, and practice the arguments that they wanted to bring forth. To be more specific, students had found it difficult to (1) plan for and write counters to the lines of debate their opponents could potentially bring out, (2) look for evidence or counter-arguments that would support their positions, (3) push past feelings of confusion when

Table 1. A subset of the themes that arose from the responses of 28 undergraduate students who had completed a debate activity where they (in groups) researched both sides of a science-related issue and subsequently argued for one of them (with no indication of which one they would be supporting until the day of the debate) in front of their classmates. This table lists the themes associated with attitudes and feelings towards the activity's structure.

Respondent wrote that they…	Number of Respondents
Attitudes and Feelings towards the Activity's Structure	
The Activity was Difficult/Work-intensive	
• Were surprised at how some aspects of the activity were more difficult than they expected, specifically having to…	18
○ …take much time to prepare for the debate	14
○ … plan for and create counters to possible arguments from the opposing debate team	7
○ …organize their researched arguments and points into a logically cohesive and concise debate plan	7
○ … search for research and arguments that would support their positions	5
▪ …specifically pro-science positions	2
○ …push past feelings of confusion when preparing to argue for a side they did not agree with	2
○ …spend enough time preparing to ensure that all team members were comfortable when it came time to debate	2
○ …coordinate how all team members would present	1
○ …rely on their teammate to pull their weight in the activity	1
The Activity was Fair	
• Felt that the workload was fair/reasonable instead of heavy	3
○ …and even if the activity was hard, it was their job to push through — after all, they may need to communicate tough subjects in the future	1
The Activity was Easy	
• Were surprised by how easy the activity was compared to what they expected	3
○ …and were surprised how comfortable they were through the activity	1
○ …but they loved to debate and publicly speak in the first place	1
The Activity was a Positive Learning Experience	
• Had positive feelings towards the activity	14
○ …and liked how they had to prepare for both sides of a debate	8
▪ …and enjoyed/found it interesting when researching other (non-science) perspectives	4
• …and had fun getting into the persona of someone holding an opinion they did not agree with	1

preparing to argue for views that they did not agree with — akin to how (as Taddicken and Wolff [2020] discuss) one may feel distressed (or, in other words, in a state of cognitive dissonance) when encountering scientific information that counters pre-existing views or knowledge — (4) figure out a logically cohesive and concise (i.e. fitting in the activity's time requirements) narrative to use for the debate (especially as there were so many possible routes students could have taken due to the freedom that the course instructor had given them to develop any debate strategy they wanted), and/or (5) work with their team (e.g. depending on everyone to pull their weight, preparing enough for everybody to be comfortable and on the same page for the debate).

"It took SO much research and prep - to have arguments I could be proud of, Aparna and I spent nearly twenty-four hours of preparation." [Student 7]

However, while most respondents thought some of this activity's aspects were difficult, three still thought of it as fair, describing the workload as reasonable instead of heavy (**Table 1**). As one of them adds, regardless of how bad things were going (in their case, they had a hard position to argue for), it was "[their] job to come back from that." After all, they may need to communicate tough subjects in the future, so they might as well take the opportunity to practice now. Three other respondents had even found that (and were surprised by how) the activity was easy and potentially even comfortable.

Such characterizations of comfortableness contrast with how most (i.e. 15) respondents had mentioned feeling stressed, panicked, worried, nervous, and/or generally uncomfortable during the debate (**Table 2**), with eight of them going so far as to name these negative emotions as the cause of their in-debate communication fumbles (e.g. forgetting to say words, not matching the tone of their partner, not paying attention to their opponent's arguments and subsequently being unable to counter, unintentionally making distracting body movements).

"I think I looked very calm and in control but inside I was dying." [Student 21]

Table 2. A subset of the themes that arose from the responses of 28 undergraduate students who had completed a debate activity where they (in groups) researched both sides of a science-related issue and subsequently argued for one of them (with no indication of which one they would be supporting until the day of the debate) in front of their classmates. This table lists the themes associated with feelings of (1) self-efficacy in communicating science and of (2) motivation in wanting to learn.

Respondent wrote that they…	Number of Respondents
Feelings of Self-Efficacy in Communicating and/or Debating Science	
• Were surprised at being able to confidently present	16
○ … as they were nervous or stressed before and/or during the activity despite seeming confident on the outside	13
○ … as they had never debated before this course.	1
• Felt stressed, nervous, or uncomfortable during the debate	15
○ … and were so stressed that they accidentally made mistakes	8
• Became more confident and comfortable with public speaking thanks to the activity	6
○ … and appreciated having a learning opportunity where they could immerse themselves into the stress and anxieties of public speaking	3
• Realized that they were not yet a good science communicator	1
Feelings of Motivation to Learn and Participate in the Activity	
• Promised to keep their mistakes/weaknesses in their performance in mind for the next time they need to communicate science	6
• Felt motivated to participate in the debate	4
○ …and also felt motivated to participate more in other courses	1
○ …and were excited to share their arguments with the rest of the class	1
• Felt that the activity did not have “any real stakes”	1
• Were more interested in winning the debate for the sake of wanting to win, rather than achieving a high grade	1

Thirteen of these respondents were able to push through such emotions (**Table 2**), subsequently reporting that they managed to confidently communicate to the rest of their classmates. On the other hand, one of the respondents had faltered, subsequently realizing that they were "still far from being a good science communicator." Still, three respondents had actually appreciated how stressful/anxiety-inducing this activity had been, finding their performances in the face of such emotions having enhanced their sense of self-efficacy.

"Being able to articulate myself in an engaging way under pressure while people are watching you was a nerve-racking thing for me, and I feel that being in those moments of high stress helps me grow more confident as a science communicator." [Student 15]

Stress, anxiety, and other negative emotions came about in spite of the fact that — as one student felt — the debate activity did not have "any real stakes" — i.e. it was just a practice session for them instead of a real-life situation with actual consequences (e.g. publicized debates where a loss is recorded forever). However, as another student wrote, there are some stakes in the form of whether or not a high mark would be achieved. Yet, the same student declared that grades had not been of their concern during the activity. Instead, they were motivated to perform well because they had wanted to win their debate. In total, only four respondents mentioned any feelings of motivation to learn/participate in the debate activity (**Table 2**), with Student 25 going so far as to say that their motivation extended to wanting to participate more in other courses. With that being said, six respondents — having reflected on the mistakes they had made during the debate — expressed feeling motivated to better themselves, promising to work on their now-discovered weaknesses for the next time that they would need to communicate science to a public audience.

In total, all respondents reported learning something (e.g. public communication skills/rhetorical strategies, insights about themselves) that would aid them in future endeavours such as arguing in support of a position or engaging an audience on both oral (e.g. debates, interviews) and written (e.g. grant applications, commentary on government policies) media (**Table 3**). However, it should be noted that all respondents had been prompted by the survey to identify how the skills that they learned during the activity would help them communicate science in the future. Yet, given the open-ended nature of the survey, the respondents had the

Table 3. A subset of the themes that arose from the responses of 28 undergraduate students who had completed a debate activity where they (in groups) researched both sides of a science-related issue and subsequently argued for one of them (with no indication of which one they would be supporting until the day of the debate) in front of their classmates. This table lists the themes associated with the respondents' behavioural intentions for post-activity science communication as well as their reactions to how they communicated science during the activity.

Respondent wrote that they…	Number of Respondents
Intentions for Post-activity Science Communication and/or Debating Behaviours	
• Picked up communication skills and competencies that would aid them…	28
○ …in arguing in support of a position	16
○ …in engaging future audiences/listeners	12
○ …as they had never comprehensively researched/thought about the positions that they did not agree with	2
○ …as they had never debated before in their life	2
• Found what they learned to be relevant to their current circumstances…	4
○ …as they discussed science issues that affected society as a whole	3
○ …as they were already applying the skills to scenarios outside of the activity	1
Reactions to In-debate Science Communication and/or Debating Behaviours	
• Recognized their performance to have weak points	28
○ …and were surprised to have performed worse than they had expected	8
▪ …after watching a video of their debate and seeing that they…	7
• … presented with low energy	1
• … coughed a lot	1
• …used filler words	1
• …did not make much eye contact with the audience	1
• …spoke too quickly	1
• …made random distractive body movements	1
• …displayed low passion	1
• Were able to recognize after watching a video of their debate that their performance was not as bad/good as they had initially thought	23
○ …and were surprised how some aspects of their performance were better than they had thought as …	19
▪ …they were not as nervous on-camera as they had felt	12
• …and they actually looked comfortable and confident	11
○ …as well as appearing to have fun	1
• …and they looked professional	1
▪ …the mistakes they made were not that noticeable	5

option to disagree with the question should they wish too. For example, one student had answered in response to a question asking them to name a weakness in their performance that they did not have any overall.

Regardless, four respondents still organically (i.e. outside of the prompt) foregrounded ways with which they had found the skills they learned to be relevant to their circumstances (**Table 3**). To be more specific, three of them referred to issues that affected society as a whole (e.g. climate change, the anti-vaccination movement, social media), while the fourth respondent pointed to how they were already leveraging the skills that they learned in family discussions about topics such as “bee conservation” and “pseudoscientific crystal therapy.” Adding on, this respondent also brought up how they were conducting their own out-of-class investigation on effective means of public communication/rhetoric:

“This [activity] led me to looking into the means of convincing people, and I uncovered the basic concepts of ‘pathos’, ‘ethos’, and ‘logos’, that is to appeal to the audience's sense of emotion, ethics, or logic.” [Student 27]

With that being said, it should also be noted that all respondents had recognized weak points in their completion of the activity although this was, again, explicitly prompted by the survey (**Table 3**). Regardless, eight respondents still organically brought up their faults, with one noting how surprised they were at (1) their difficulty in trusting their partner’s ability to pull their own weight in the activity and (2) how they still stumbled during the debate despite having practiced. Meanwhile, the other seven had watched videos of their own debate performance and realized that they had not performed as well as they had expected. To be more specific, they relayed how looking at themselves from an audience perspective caused them to notice that they presented with low energy, coughed a lot, used filler words, did not make much eye contact with the audience, spoke too quickly, had random distracting body movements, and displayed low passion — behaviours that they did not pick up on in the moment of their debating.

"Watching myself mumble to the floor and huddle in a ball made me cringe, and I felt that if I saw someone with that posture in a real televised debate, they would not be very convincing to me. I was surprised by how much this detracted from the passion and understanding I had in the topic. This passion barely shows when the body is held this way." [Student 27]

Not all respondents had the same negative reaction as the cringing Student 27 when watching their respective videos. In fact, most (i.e. 19) had reported recognizing that some aspects of their debate performance looked better than they had felt while in the debate (**Table 3**). The most common reason for such reactions was the realization that they did not appear on video to be as nervous as actually were during the debate, instead seeming to be comfortable, confident, having fun, and/or "professional."

"When watching the video back, I was actually pleasantly surprised to see that I was more confident and a stronger debater than I had come out thinking I was. I think watching myself back was good, as I tend to walk away from these things thinking I did much worse than I did." [Student 25]

Another cited reason was how mistakes made by students may not actually be noticeable from a third-person perspective (**Table 3**). For example, one respondent recounted how they had missed a concluding sentence in their opening argument, thereby "ruining" it. Upon a video review of their performance, they realized that this was not noticeable at all from the audience's point of view. Likewise, three other respondents reported how their awkward pauses and stumbling over of words were not — as one of them worded — "as bad as [they] thought."

"In moments where I felt that I had stumbled or was panicking you really can't tell. It's very interesting to see the difference in perspectives of those doing the debate to those watching." [Student 18]

In total, most (i.e. 23) respondents discussed how reviewing a video of their debate allowed them to recognize that their performance may not have gone as badly/well as they had perceived it to be while they were actually debating (**Table 3**).

Table 4. A subset of the themes that arose from the responses of 28 undergraduate students who had completed a debate activity where they (in groups) researched both sides of a science-related issue and subsequently argued for one of them (with no indication of which one they would be supporting until the day of the debate) in front of their classmates. This table lists the themes associated with the respondents' understanding of public science communication's importance.

Respondent wrote that they…	Number of Respondents
Understanding of Public Science Communication's Importance	
• Acknowledged the importance of public communication skills	25
○ …and the activity taught or surprised them with this lesson	22
▪ …with a key takeaway being that one cannot win a debate/convince others by just passing along facts to the audience (i.e. they need to be engaging)	10
• …and were surprised that they had to spend more time on deciding and practicing how to communicate their points and arguments rather than actually finding facts	5
○ …and were not familiar with using social science to improve their communication	2
○ …learned that winning a debate is more about communication rather than bringing accurate or correct facts	2

Student's Knowledge of General Principles for Public Science Communication

Most (i.e. 25) respondents acknowledged in their reflection the role that public communication skills can play in debating (**Table 4**) — specifically in that providing comprehensive accurate information is not a sufficient strategy for trying to engage an audience or to convince its members to support whatever position one is arguing for. Out of these 25, most (i.e. 22) explicitly pointed to how their experience in this activity taught or surprised them about the importance of certain aspects of public communication/rhetoric. Adding on, a subset of respondents had noted that a key learning outcome for them was that one cannot win a debate/convince others by just repeating facts to audiences — debates would not be won solely on the basis of how accurate one's facts were or how many they were able to bring up. Such information needs to be communicated in an engaging manner.

"I learned that the way you communicate is far more important than the content that's being said...I will constantly be keeping in mind how the people I'm communicating with see me and how I'm coming across. To be able to communicate science is to be able to communicate PERIOD." [Student 16]

Extending such a realization, some respondents relayed their surprise at how they had spent more time on deciding and practicing how they were going to communicate than researching what they were going to communicate (**Table 4**). This was not exactly a simple or easy process given how a subset of them had indicated that they were not familiar with incorporating social science into their communication practices. With that being said, respondents still managed to collectively refer to several principles of general public science communication throughout their reflections:

(1) Be concise
(2) Be understandable
(3) Include metaphors and stories
(4) Incorporate emotion and personal connections to the audience
(5) Face the audience
(6) Project a personality and passion
(7) Be able to adapt and stay calm
(8) Know your material and be ready to improvise
(9) Work with your partners as a team

Be Concise. Twelve respondents touched upon the importance of being concise when communicating (**Table 5**). Accordingly, a subset of them identified one of their strengths being their ability to limit the number of points that they discussed and/or keep them concise, preferring not to (as Student 4 words it) — "overload" and subsequently lose the attention of the audience — a concern shared by publications such as Collins (2004).

Table 5. A list of public science communication principles/rhetorical strategies that had been discussed in reflections written by students who had just completed an activity where they (in groups) researched both sides of a science-related issue and subsequently argued for one of them (with no indication of which one they would be supporting until the day of the debate) in front of their classmates.

	Number of student reflections that…			
	Discussed the principle	Recalled learning more about and/or being surprised by new information about the principle	Identified following the principle as a strong point of their performance	Described following the principle to be difficult and/or a weak point of their performance
<u>General Principles</u>				
Be concise	12	6	7	6
Be understandable	16	4	12	4
Include metaphors and stories	10	5	2	1
Incorporate emotion // Personally connect to the audience	13	6	8	2
Face who you are talking to	12	0	8	5
Project a personality // Project passion	17	4	6	9
Be able to mentally adapt // Be able to stay calm	18	3	9	3
Be prepared	25	10	8	10
Work with your partners as a team	10	3	2	6
<u>Debate-specific Principles</u>				
Actively listen // Know your audience	19	9	0	2
Know the other side…	28	27	10	15
…to understand why people buy into the other side	5	5	0	0
…to have a nuanced understanding of the topic	14	14	0	1
…to be better prepared to respond to the other side	24	19	10	14

"We found heaps of points for both sides but really had to narrow it down to only what we thought was essential and would catch the audiences' attention." [Student 15]

Contrastingly, some respondents had also struggled with this principle (**Table 5**). While one lamented presenting too few arguments and having a surplus of time, most of them faced the opposite issue, having indicated regret in that they should have presented fewer points as they all perceived themselves as having almost lost (or actually losing) their audience's engagement. One even partially attributed their loss in the debate to this strategic error.

"It can be difficult for even a science student to sit through a list of facts being read, so it's no surprise that it's even harder for the general audience to stomach." [Student 12]

Be Understandable. More than half of the respondents (i.e. 16 of them) discussed the principle of being understandable to their audience (**Table 5**). Those who were able to adhere to it recounted employing strategies such as enunciating clearly and using conversational, easy-to-follow language. On the content-related aspects of their performance, these respondents also reported using analogies, examples, anecdotes, models, and even physical demonstrations (e.g. hand gestures) to better explain concepts being presented.

"Often times, presenting the facts just isn't enough to win over an audience. Relating complex ideas back to well-known ideas is a strong strategy, and using anecdotes that hit close to home is another way to win over the audience." [Student 12]

However, some respondents also spotlighted their struggles with being understandable. Some reflected on how they failed to clearly define the technical concepts and terminology that they had referred to during the debate, while others pointed to how they had provided too many details. Consequently, both of these groups observed that they had confused their audience. Adding on to the audience's confusion, some had also found it difficult (or were unable) to present points and ideas (or spontaneously create new ones during the debate) that could match the overarching structure of their overall message, leading to arguments that were — as one student characterized — "scattered."

Include metaphors and stories. Metaphors and stories were the least-discussed principle (**Table 5**), with this scarcity coming about in spite of how the course instructor had spotlighted in multiple instances during the course their potential in engaging audiences — an endorsement in line with publications such as Collins (2004) and Nisbet (2009). Regardless, a few (i.e. five) respondents still reported their success in adding stories, catchy arguments, sound-bites, and "powerful keywords", with some adding on how they had been surprised at the fact that such rhetorical devices could take precedence over factual information.

"I was surprised by how much effort I put into making my arguments sound catchy as opposed to making sure they were fact-based. This made me realise how important it is to have good sound-bites to make sure the arguments have an impact on the audience." [Student 19]

A subset of these students, while having incorporated stories into their arguments, felt that they should have told even more. After all, one participant in particular had obtained a first-hand experience on the power of anecdotes, having almost bought into ideas that they disagreed with.

"When reading up on the dangers of [genetically modified foods], I had to pause on a few occasions because some stories seemed to raise some genuine concerns that actually had me questioning myself. Of course, some further fact checking proved them to be false or twisted out of context, but it was surprising to see how easily I could be swayed by emotionally charged language or personally relatable anecdotes." [Student 12]

Incorporate Emotion // Personally Connect to the Audience. In line with recommendations from literature such as Wirz (2018), a total of 13 respondents acknowledged how incorporating emotional appeals and a personal element (i.e. connecting to the audience) into their arguments in general (as opposed to limiting themselves to just anecdotes/stories) can facilitate engagement with the audience (**Table 5**). Accordingly, most of these respondents pointed to how they had adhered to this public communication principle via metaphors, stories, and the vocal tone that they spoke with. Still, some reflected on how they should have attempted to relate more to their audience's personal experiences.

"This activity really drove home for me that when it comes to being convincing, you need an emotional impact. The debates showed me that no matter how logical and fact-based some arguments were, they weren't as effective as those that used an emotional or personal appeal." [Student 19]

Face the Audience. In line with Beebe (1974) — the results of which had indicated that a speaker's amount of audience-oriented eye contact had a positive relationship towards their perceived credibility (i.e. how qualified and honest they seemed to an honest), 12 respondents reported that their engagement strategies for the debate included directly facing their classmates and attempting to maintain eye contact with all of them (**Table 5**). Most were able to do so, subsequently spotlighting it as a strong point of their performance. The remaining struggled with it, lamenting in their reflections that they had spent too much time reading directly from their notes as opposed to looking at the audience. Moreover, they all admitted that they found it challenging to memorize what they wanted to say and confidently re-state them, with one adding that it was difficult to maintain eye contact with every single member of the audience.

"I also wish that I had attempted to make more eye contact with the audience; while I had my parts memorized, I still looked down at my paper often as a safety net and I thought it really took away from what I was trying to say." [Student 5]

Project a Personality // Project Passion. Over half of the students (specifically 17 of them) brought up how injecting passion and personality into their debate (as opposed to being bland and boring) was a path to engaging audiences (an insight shared by publications such as Collins [2004] and Concannon and Grenon [2016]) (**Table 5**), with one of them adding that they had to even intentionally put on a persona. After all, as another noted as a lesson from this activity, audiences can pick up on whatever character the debaters were projecting and react accordingly (i.e. by supporting/believing [or not] whoever was talking). As such, several respondents relayed how they were able to put on a respectful, professional, passionate/enthusiastic, or light-hearted/humourous persona. Another student also described how they had accidentally put on an endearing character:

"I learned that the way you communicate is far more important than the content that's being said...I will constantly be keeping in mind how the people I'm communicating with see me and how I'm coming across. To be able to communicate science is to be able to communicate PERIOD." [Student 16]

However, respondents also highlighted some struggles with this principle, both on a team-wide (i.e. they could not keep their personalities/styles consistent between all members of the team) and individual level. Extending on the latter point, a subset of respondents had regretted not presenting themselves (both orally and physically) as energetic, dynamic, or passionate/enthusiastic enough about the topic, with others foregrounding how they seemed too "stiff" and rehearsed to be perceived as authentic/credible by the audience.

"I would say my weak aspect would be my body language. After I was done speaking and [it was my partner's turn,] my body language gave off the impression that I didn't care. When I focus I also cup my eyes which could be seen as me [resting] on my hands." [Student 3]

Be Able to Mentally Adapt // Be Able to Stay Calm. As Bodie (2010) advises, being able to stay calm, stay focused, and adapt in the face of any difficulties that come one's way is an important skill that can help a speaker maintain their ability to communicate and engage their audience. Accordingly, over half of the respondents (specifically 17 of them) touched upon this principle in their reflections (**Table 5**), although a subset of them were unable to maintain their cool and subsequently hampered their debate performance.

"When taking a pause before my last sentence my partner started saying his piece. This rattled me a little bit and shook my confidence during the rebuttal, in which I missed some important points that I had planned on addressing." [Student 5]

With that being said, half of all respondents considered themselves to have stayed calm throughout the debate — for example, by keeping collected enough to recover after committing mistakes (e.g. they stumbled over words, the debate had not gone as they had planned, they had to abandon most of their scripted/planned arguments).

"Tripped over my words a bit in the first minute, but it definitely felt a lot worse than it looked. Made a decent recovery after and the rest of the debate proceeded relatively smoothly." [Student 12]

Others had stayed calm despite the fact that their position seemed challenging to argue for and/or that they were disadvantaged by their lack of pre-existing experience. After all, as one of them had written, no matter what hardship they faced over the course of the debate it was "[their] job to come back from that."

Be Prepared. In line with the recommendations of Collins (2004), most (i.e. 25) of the respondents recognized (with a subset identifying as a key takeaway for them from this activity) that it is important to be prepared enough to be comfortable when it came time to debate — either by (1) practicing communicating what they want to say or (2) researching enough that they become familiar with the issue being argued and can create new points to discuss on-the-spot if any complications (e.g. unexpected counter-points from the opponents) arose (**Table 5**). As some of the respondents reflected, it may have been surprising how much time and effort the preparation process takes, but it was still important for their debate performance.

"I think learning how to be prepared was the critical communication skill learned in this project, when you aren't is when nerves start to show. Really researching all avenues and practising orally are applicable skills to apply to any communication problem and crucial to doing well." [Student 24]

For one student in particular, "being prepared" entailed having a script. Accordingly, one of their lessons from this activity was how important scripts were. In total, just over a quarter (i.e. 8) respondents recounted using a script (or reading from their prepared notes) when it came time for them to speak. They struggled with remembering all of their points, with one of them (who had actually memorized what they wanted to say) likening their script to a "safety net." Corroborating them, another student that had foregone using a script had also noted in their reflection how it had been difficult for them to communicate all of their points.

However, in their reflections, half of them expressed distaste for their script usage, stating that it "took away from what [they were] trying to say" and made them seem awkward and/or less authentic to the audience. After all, as other respondents had observed, one cannot always rely on a script — in the context of the debate activity, several students had to make up points and arguments on-the-spot. This was especially apparent in the rebuttal portion of the activity as they would not be able to completely predict beforehand what their debate opponents would bring up and thus would be unable to have a pre-configured script.

Work With Your Partners as a Team. Ten respondents brought up their competency/struggles with the teamwork aspect of this activity (**Table 5**). While this principle may not be explicitly associated with communication, past literature such as De Clippele et al. (2021), Illingworth and Roop (2015), and Mackay et al. (2020) have pointed to contexts where scientists will need to know how to efficiently collaborate amongst themselves in order to effectively prepare for and undertake public communication activities (e.g. outreach programs). Accordingly, some respondents were able to learn more about teamwork, either before the debate (e.g. working together to prepare arguments) and/or during (e.g. interacting with them in a coordinated fashion).

"This [activity] also taught me more about teamwork. You need to trust your partner. I didn't know my partner super well, and we had different styles, but we had to trust each other."
[Student 14]

While some viewed their competency in teamwork as a strength in their performance, more respondents had struggled with this aspect of the activity. For example, one respondent was surprised by how difficult it was for them to trust that their partner was able to pull their own weight. Others had struggled with making sure that all of their respective groups' members were on the same page (i.e. had the same, consistent communication style; knew who would discuss what), having found that this added extra time and complexity to their preparation process.

"I think the teamwork aspect was a lot more in depth than I had anticipated. I knew I didn't want to simply have a script, and that meant making sure that both members of the team were comfortable remembering what to say, or being able to roll with the punches and improvise from the info we have. I know that I am fairly decent at this, but working as a team to ensure that we both felt comfortable was more difficult." [Student 14]

Students' Knowledge of Debate-specific Principles for Public Science Communication

Actively Listen // Know Your Audience. Most (i.e. 19) respondents touched upon their attempts at actively listening to their opponents and knowing their audience (**Table 5**), thereby guiding their determination on what they would need to discuss/rebut to win their debate. However, some relayed their struggles with the former principle, having failed to actively listen to their opponents, missing the points that their opponents were pushing, and subsequently regretting how they were unable to provide the proper counter-arguments.

"Meanwhile, the other group was going. I didn't catch the fact that they were driving the point home with the economic issue. I should've listened better." [Student 21]

On the other hand, most respondents (i.e. 17) had found themselves able to adhere to the latter principle. One of them had even reflected how surprised they were to learn that debates are not about throwing as many facts as possible to the audience. Instead, they continued, speakers need to craft arguments and points that cater to their audience's interests, values, and emotions in order to engage them and convince them of the speakers' positions. Otherwise, one may run the risk of boring and/or not connecting to them — an insight corroborated by commentary from publications such as Fischhoff (2013) and Klöckner (2015) as well as the reflections of three other respondents.

As other reflections also noted, speakers also need to recognize that science-related issues may have socioeconomic and political aspects, meaning that one would need to touch upon more than just the science.

"For a topic so broad and new as [Genetically Modified Organisms] there were a lot of avenues unexplored and I think just dismissing that as pseudoscience really shapes how we as scientists are viewed by public skeptics." [Student 16]

Yet, another respondent (also tackling Genetically Modified Organisms (GMO; this student was specifically referring to genetically modified foodstuff) came to a different conclusion. They had instead viewed opposition to their pro-GMO stance as strictly anti-science (as opposed to dealing with subjective emotions like fear), and had accordingly steeped their arguments with hard scientific evidence. Still, such a strategy does have merit considering how their audience was technically comprised of science students — it is not entirely unreasonable to assume that they would value science-based arguments over emotional ones.

Regardless, some respondents who had argued for a "non-scientific" opinion observed over the course of their debate preparation that winning did not necessarily equate with telling the truth. In fact, they realized that lying about the facts (e.g. by treating any scientific evidence/arguments as fake or a conspiracy) and playing up the emotional aspects of the issue can be just as successful at convincing audiences (and easier to do) than telling the scientific truth.

"I had even practiced [debating] with many friends and family members, and indeed found arguing the Round-Earth side more difficult, simply because it's hard to argue with utter nonsense. And with the Flat-Earth side, worst case scenario, I could have answered any and everything with a wacky conspiracy theory. As such, this exercise was not only one in constructing effective arguments and in improvisation, but again, in what makes a pseudoscience and how they can be so successful." [Student 2]

Know the Other Side. All respondents recounted having to learn more about both sides of their topic and subsequently becoming more familiar with their views (**Table 5**). After all, it was a requirement for the activity. Furthermore, as one respondent had noted, if the students wanted to argue in a way that would be able to convince someone opposed to their views as opposed to simply preaching to the choir, they would need to (in the respondent's words) "understand where the other side is coming from, sympathize with that, and explain [the student's] side in a way that does not conflict with [the values of whoever the student is trying to convince]." Such a view is in line with studies such as Morgan et al. (2018), which had sought to better understand anti-science beliefs for the explicit purpose of informing public communication efforts that seek to address such opinions.

Accordingly, multiple respondents credited this activity with teaching them (1) about the importance of conducting research on opinions beyond those they already supported and (2) how to actually conduct such research in the first place. As three of the respondents had reflected, they never would have taken any in-depth looks at the "non-scientific" views that they did not support were it not for this activity. With that being said, 24 other respondents (for a total of 27) mentioned how having to research the other side in order to prepare for the debate facilitated them in discovering and being surprised by new (to them) information about the issue.

"I was surprised to see how many ways social media can affect mental health that I became more aware of how often I used my social media." [Student 23]

To be more specific, the 27 respondents listed three general learning outcomes from having to explore views beyond their own. The least commonly-discussed of these (by four respondents; **Table 5**) was their acquisition of **an understanding on why people would buy into the other side**, with one expressing surprise at how they had developed empathy for such people. After all, as other respondents observed, the other side can have compelling arguments.

"[Supporters of Flat Earth Theory] are pretty good at making their arguments seem legitimate, and so I caught myself thinking that I could almost understand how someone who has no background in science whatsoever and maybe hasn't bothered to conduct the research on the Round-Earth side much might believe it." [Student 2]

The second least-discussed learning outcome (reflected on by 12 respondents; **Table 5**) was their gain of **a more nuanced understanding of the topic that they were debating**. To them, the issue was not actually as black-and-white as they had thought, and the other side's points and arguments were reasonable. In fact, a subset of these respondents reported having changed their mind about the issue, becoming less firm in their opinions, and/or declaring that they were unable to fully support one side or the other.

"Since my group was looking at if veganism was healthier in humans, I was very surprised to see the differing viewpoints that exist surrounding this topic- and the ways that both sides can really be right when approaching the question from a different angle." [Student 26]

Respondents also learned more about recognizing and reducing their own personal biases surrounding an issue, with some of them even reporting how surprised they were when they realized that the issues they were debating were not entirely contingent on science. To be more specific, instead of just being a case of scientists equipped with facts and evidence going against anti-science conspiracy theories there were other aspects at play such as political, economic, ethical, and social reasons, with everybody having differing opinions on what matters the most.

"[My research] highlighted the fact that complex issues like population limitation on a global scale are almost never black and white, and there are many ethical and logical values and predictions that vastly change how the issue should be addressed, depending on who you ask." [Student 27]

However, not all respondents shared such a view. As previously described, one student's research actually simplified their understanding of their debate issue about the safety of GMOs. In essence, they ended up focusing only on the science aspects of the issue, believing that the only reason why people were against GMOs was that they had bought into conspiracy theories due to their lack of a science background.

"However, after researching the topic, I realized that the opponents of GMOs do not really have too much science to back them up […] *The reason why so many people do not trust GMO is that the opponents of GMO advertised the anti-GMO arguments using conspiracy theories that can easily convince the general public who lack a strong scientific background."* [Student 28]

The most commonly-discussed learning outcome (brought up by 24 respondents; **Table 5**) was having **better preparation for responding to the other side's points**, with half of these respondents having identified learning about this effect as one of their main lessons from this activity and ten of them having spotlighted their proficiency for being prepared as a strong point in their performance.

Building on, the respondents pointed out how they were able to become more familiar with possible routes that the opposing debate team could take to attack their positions (i.e. weak spots in the arguments) and to become ready to switch from one to another to match whatever arguments came their way. Accordingly, the respondents were able to (1) prepare their defenses in advance (alleviating somewhat the pressure of having to create rebuttals on the spot), (2) fill in the holes of their arguments before the debate even started (limiting the ability of their opponents in attacking them), (3) pre-empt their opponents' arguments (thereby reducing the amount of arguments available for the opponents to employ), and (4) frame their arguments in a way that would be more easily accepted (i.e. does not conflict with values) and understood by listeners.

"Even if we knew in advance which side of the debate we would have to argue, I think preparing both the way we did prepared us much better. Having an idea what approach the opposing team was likely to take gave us a solid advantage, and took away a lot of the element of surprise that could have thrown us off balance." [Student 2]

No matter what the purpose of their preparation was, half of all respondents stated that they were surprised about how difficult they found the process of preparing rebuttals, presenting them in the debate, and/or creating new rebuttals on-the-spot to be, with a subset of them also identifying their struggles with this as a weak point of their performance. As the respondents observed, it can be hard to predict all of the possible things that the other side would say and counter them accordingly.

"It was definitely a large amount of work to prepare for both sides of a debate because every point you come up with for one argument you need to think of how it may also be countered by the opposition." [Student 17]

Respondents also brought up how further obstacles in the preparation process can come about in the form of needing to somehow structure their various arguments into a logically cohesive yet flexible narrative that can fit into the overarching structure of their arguments and take into account possible rebuttals from the debate opponents.

"By preparing for both sides of the arguments, I found that it is relatively easy to find pieces of evidence to support the claims, but it is challenging to organize all the information to have a logical flow, especially under the context of a debate. Because you cannot just present your arguments, you also have to refute the opponents' points at the same time, which I found quite challenging to do." [Student 28]

Students' Debate Videos

In analyzing the video recordings showing the debate performances of the three chosen students of interest (respectively referred to as Student 25, Student 27, and Student 28 in accordance with their randomized survey identification), three observations about how the debate activity was experienced became apparent.

The Experience Can Be Stressful

Matching one of the sub-themes that arose from the students' post-activity reflections, the first observation was about how the activity could be stressful, with this being best demonstrated by Student 28's debate performance. To be more specific, Student 28 and his partner had found themselves arguing about the safety of GMOs against a team whose members were adept science communicators. In essence, the footage of the debate showed their opponents having simultaneously (1) presented with energy and passion (e.g. being emotive in vocal intonations and hand gestures); (2) personally connected to (via directly speaking to) the audience; (3) employed metaphors, catchphrases, and stories; and (4) employed emotional appeals (specifically scare tactics that would elicit fear in the audience about GMOs).

In addition to being commonly discussed in the 28 students' reflections, such public communication/rhetorical strategies also fall in line with literature such as Collins (204), Hood and Forey (2005), Tannenbaum et al. (2015), and Zhang (2021) that have identified them as avenues for connecting to, engaging, and convincing an audience. This scholarly endorsement is further corroborated by the audience feedback to Student 28's debate opponents.

"That [story about a teenager dying from genetic modification] … somehow I just got chills […] *it felt personal that he died* […] *at the end of the day you can say all the facts you want but if you appeal to the audience emotionally (which you did to me) then I think you will have convinced me."* [Student audience member addressing the debate opponents]

However, when it came time for Student 28 and his partner to counter-argue, audience reactions towards their overall communication style were not as stellar. After all, as seen in the video recordings, Student 28's manner of speaking was monotonous and inexpressive, especially when compared to his debate opponents.

"But [watching the debate] is so hard because you're like 'I want to agree with you; start dancing or something...do something like...watch these guys...like come on!" [Student Audience Member addressing Student 28's team and advising them to "watch" how their opponents communicated]

As he spotlighted in his post-activity reflections, the pace at which he had spoken was also fast — something that noticeably contrasts in the debate's video recording with the slower, more relaxed talking speed of his partner. Accordingly, he included in his reflections a resolution to "talk a little slower and be more relaxed next time." After all, his overall nervousness was what he identified as a factor that harmed the quality of his performance.

"Although I had prepared for lots of arguments for the debate, the moment when I spoke to the audience, my mind just went blank, I was too nervous to recall some information that I prepared before the debate." [Student 28]

His nervousness in the form of his quoted inability to recall is apparent in the video recording of the debate, considering how he can be seen mostly reading from his script and rarely taking his eyes off of it in order to establish eye contact. Also observable in the video is how (1) his speech had been full of filler words (e.g. "um", "uh) and pauses, (2) his points and arguments had been at times difficult to hear/interpret due to his tendency to mumble and taper off his speaking volume at the end of sentences, and (3) he fidgeted his body throughout the debate.

All of these behaviours — according to publications such as Collins (2004) and Hofmann et al. (1997) — are signs of anxieties and nervousness over public speaking, which is to be expected. After all, such a task is a stressful one that can physically affect one both physically (e.g. increased heart rate and blood pressure; Lacy et al., 1995) and mentally (e.g. reduced ability to think; Arnsten et al., 2012), even if it is in a context as — as one student had put it — "low stakes" as this in-class debate activity. This latter mental aspect is what Student 28 and seven of his classmates attribute as the cause of their committing of mistakes during their performances. On the other hand, three students credited the stress and anxiety of this activity as something that allowed them to become more confident and comfortable (i.e. higher self-efficacy) in public speaking.

How could there be such a discrepancy in students' reaction to the stressful nature of this activity? As Rudland et al. (2020) write, stress can be conducive to learning. Citing previous research such as Cahill et al. (2003) and Kaiseler et al. (2009), Rudland et al. (2020) foreground how experiencing some stress can result in one having enhanced motivation and mental functioning. However, too much stress can also lead to lower academic ability (citing LeBlanc [2009]). Further complicating matters, they (citing Jones and Johnston [1997]) add that what causes one to feel little stress may cause another to feel a huge amount of it. In relation to the source of stress that is this activity, perhaps Student 28 belonged to this latter category.

Regardless, the consequence of his stress-mediated poor performance led him to reflect that they were "still far from being a good science communicator." In other words, his sense of science communication self-efficacy was low. Such a learning outcome is concerning as literature such as Besley et al. (2018), Besley et al. (2019), and Rodgers et al. (2020) have all called attention to how self-efficacy has a positive relationship with a willingness to partake in public science communication. As such, Student 28 and any other student who may have low self-efficacy as a result of their performance being lower quality than they expected may never publicly communicate science again. Moreover, given how self-efficacy is also linked to learning motivation (Wang et al., 2008), there is the possibility that they may also not seek out any more science communication training courses/programs to improve on their weaknesses.

Thus, science communication instructors who wish to conduct this in-class debate activity should ensure that their class is ready for it — i.e. they are comfortable with public speaking and/or they are able to work through the nervousness associated with such a task. After all, around half (i.e. 15) of the 28 students in this study recalled having to deal with feelings of stress and nervousness while debating, and this does not take into account how most (i.e. 18) students recounted having to navigate through unexpected difficulties (and thus stress-inducing; Beck & Srivastava, 1991) throughout the activity.

Accordingly, a possible avenue to nurture this comfortableness and/or ability to adapt to nervousness is in Reis et al. (2015). To be more specific, the authors had examined the anxiety surrounding student participation in science fair competitions. They note that having positive experiences in previous science fairs can be conducive to a student being more adept at managing their anxiety in such science communication contexts. Therefore, instructors organizing future renditions of a in-class debate activity could consider holding smaller-scale "dry runs"/rehearsals that would not be marked/assessed before having their students perform in an actual marked/assessed debate. While these rehearsals would ostensibly have even lower stakes on account of not necessarily contributing anything grade-wise to students and of not technically being the "actual" debate activity, participants could still be motivated by — as one of this study's students reported — a drive to win regardless.

The Experience Can Be Better Remembered With the Help of Video Reviews

Matching another of the common sub-themes that arose in the students' post-activity reflections (most [i.e. 23] of the respondents had mentioned this), the general second observation pertained to how students tended to change their beliefs/opinions on the quality of their debate performance upon reviewing video footage of it. To be more specific, this study's analysis of Student 28's debate footage corroborates his assessment of how he had actually spoken too quickly — an assessment he only came to when watching said footage. Likewise, Student 25 noted how his viewing of his own debate's footage allowed him to realize that he had performed better than he had initially (i.e. immediately after the debate) thought in terms of being able to maintain eye contact and refrain from mumbling. This study's examination of his associated debate recording supports the accuracy of such an evaluation.

Such learning outcomes line up with the results of Oliveira et al. (2021) who had studied a science communication oral presentation activity in a biology course. Like in this study, the students in that course were required to watch a video of their presentation one week after the activity and then reflect on their performance in a survey. Unlike this study, they had also completed a self-assessment/reflective survey immediately after their presentation. Subsequently, the authors observed that 40.74% of the students held different overall opinions of or feelings towards how they had presented.

As the authors explain, the video reflections acted as a third-person perspective unbeholden to the distortions that human memory can fall prey to — a phenomenon that is facilitated by (as Tulving and Craik [2000] describe) how humans tend to remember in much more detail emotionally charged and stressful events such as, in the context of science communication, public speaking. Consequently, human memories tend to become biased towards these events. The study's students would have been drawing from this distorted memory in their immediate post-activity reflections/self-assessments.

However, videos are an unbiased, accurate resource that would re-present everything that had happened during a recording, not just the emotionally charged/stressful moments. As the authors report, videos would have allowed the highlighted 40.74% to have obtained a more objective perspective of how their presentations actually went, allowing them to pick up on aspects they would not have been aware of and thereafter have a more accurate view of how they communicate. Such accuracy could entail a student gaining a more positive self-perception or a more negative one (22.22% and 18.52% of all participants in Oliveira et al. [2021] respectively), mirroring what had occurred in this study.

Accordingly, science communication instructors conducting future renditions of this activity should make sure to keep this post-debate video review. Otherwise, their students may not walk away from the activity with a more accurate idea of what they did well/did not do well. With that being said, there is a limitation: such accuracy is not guaranteed as one may still mis-assess and/or miss aspects of their performance. Such a limitation is the third observation arising from this study's review of students' debate videos.

The Experience May Not Be Fully Assessed

Returning to Student 28, weaknesses such as over-usage of filler words, long pauses, monotonous speech, or lack of eye contact were nowhere to be found in his reflections and would have remained unacknowledged if this study had not checked his debate's associated recording. A similar outcome was present in this study's video review of Student 25's debate, during which they argued against the legalization of all drugs in Canada. Accordingly, their opponents had brought up various aspects surrounding the issue in order to advocate for legalization — for example, a re-telling of the successes of Portugal in reducing rates of the HIV disease upon "legalizing" all drugs as well as a discussion of how current drug criminalization laws unfairly stigmatize drug users.

However, Student 25 and his partner were able to provide rebuttals — e.g. pointing out that Portugal actually decriminalized rather than legalized drugs — while introducing new arguments that are able to attack and catch their opponents off guard — e.g. telling emotional stories about how drug addiction has ruined the life of loved ones. Akin to Student 28's debate opponent, this gained praise from the audience, whose feedback indicated that such strategies were convincing against the case for drug legalization. Accordingly, Student 25 had written in his reflections how their rebuttals were one of the strong points of his team's performance, going insofar as to say that they had "no struggle" in creating such rebuttals.

This was not exactly the case. This study's review of the footage found that both Student 25 and his partner had ignored one of their opponents' major arguments about how certain drugs (i.e. tobacco and alcohol) are still legal despite all of their dangers. Adding on, Student 25's rebuttal to his opponents' discussion of stigmatization against drug users as a justification for why all drugs should be legalized (e.g. because stigmatization causes drug users to become discouraged from seeking help for their addictions) was:

"On the point of stigmatization, we don't have to legalize something to make addiction treatment more accessible. And we don't have to do it to decrease stigmatization. Stigmatization, we all know, in many areas has decreased a lot in the past decades whether it's with addicts, LGBTQ, and racial issues…obviously." [Student 25]

Curiously, Student 25 decided to couple his counter that stigmatization against drug users with an additional notion that it has also decreased in regard to the LGBTQI2SA+ and racial minorities, capped off with a condescendingly-inflected "obviously." Ignoring how the former had no relevance to the debate (neither team had mentioned them before this instance, nor do they ever bring them up again), such a controversial point rings hollow to those (such as myself) belonging to either or both of those communities and have first-hand experience of such stigmatization (which, incidentally, may also have increased in recent times [e.g. Nguyen et al., 2020]) and may even dis-engage them. After all, several audience members had commented on how Student 28 lost their support by comparing a pro-GMO stance to a pro-nuclear energy stance despite the controversy associated with the latter (Bickerstaff et al., 2008). Accordingly, I cannot find myself agreeing with his characterization of his rebuttals as "without struggle."

With that being said, Student 25's reflections (even though it was guided by his having to rewatch the video of his performance) also placed some of his performance aspects in a worse light than reality. For example, he writes how he was "antsy" and making distracting body movements such as leg-shaking or hand gestures. However, neither his supposed "antsy-ness" or leg-shaking were visible in the video recording of his debate. Adding on, his hand gestures were not particularly disruptive, especially considering how Collins (2004) identifies them as a method of visually reinforcing/emphasizing one's point.

A similar over-negative self-assessment was present in the reflections of Student 27. While he and the other three participants in his assigned debate had received post-debate criticism from their audience over their body language, he had been the topic of most of them. Likewise, Student 27's reaction to his performance upon conducing a video review of the debate was as critical, even matching some of the feedback that he was given.

"A lot of you — and especially you [Student 27]. You were doing this [the speaker poses off-camera, but Student 27 reacts in an apparent self-inflicted joke about his posture, proceeding to lean forward and tuck his body all the way into his legs as if he was curling up into a ball] the entire time and moving." [Audience Member]

"Watching myself mumble to the floor and huddle in a ball made me cringe, and I felt that if I saw someone with that posture in a real televised debate, they would not be very convincing to me." [Student 27]

This study's video review of his performance does show examples of such — as would be characterized by Collins (2004) — distracting or dis-engaging body language. Throughout the recording, he had limited eye contact with the audience, he was constantly swivelling in his chair and pushing it back and forth from the table he is next to, one of his feet was constantly tapping (this is made especially apparent by how — as a consequence of his leg-crossing posture — this foot was up in the air and in the audience's line of sight), and — as described by one of the audience members — he periodically stretched his legs straight out in front of him.

With that being said, his posture never noticeably resembled that of a huddle into a ball, nor was his speech ever mumbled (compared with the other debaters, his speech was clearer and varied [i.e. not monotonous] and he did not appear to have used filler words nor have any long pauses between words). Incidentally, such criticisms are more applicable to the other debaters, as they had intermittently visibly hunched their heads all the way down to the table that they had placed their notes on in order to read from their scripts.

Putting together the reflection-reality discrepancies of all three students of interest, it would appear that self-assessments may not be completely accurate and comprehensive portrayals of what students actually experienced during the in-class debate activity. Such a conclusion matches that of Clarkson et al. (2018). They found that their participants — who had watched footage of both their first and final presentations in the program — rated their improvements in science communication competency at a much lesser scale than external third-party reviewers who had watched the same footage.

As such, instructors conducting future renditions of the in-class debate activity need to ensure that students do not reflect only on their self-assessments, either by the instructors providing their own feedback (after reviewing videos of the students' performances) or by unbiased third-party/external observers. While this activity's "audience feedback" portion could be considered as a third-party source, there is no guarantee that it is completely unbiased considering how all students may have pre-existing relationships/friendships.

Conclusion and Implications

In this study, I conducted a qualitative thematic analysis of the reflections submitted by 28 undergraduate students who had just completed a science communication activity where they prepared for arguing either side of a science-related issue before having to participate in in-class debates about said issue (with no choice on which stance they would take) against their classmates. Three overall themes emerged from this analysis, the first of which pertained to the activity's effect on the students' attitudes and feelings.

To be more specific, while half of the respondents had characterized it as a positive learning experience, most (i.e. 18) students relayed having struggled with some aspects of the activity. With the most commonly cited of these aspects being the overall process for preparing for a debate, future instructors wishing to conduct a similar in-class debate activity should take care to ensure that their students either (1) already have competency in efficiently conducting independent research on a subject and/or (2) have access to any help should they require guidance in their research (e.g. identifying starting points for research such as encyclopedias or literature reviews).

Regardless of difficulty, four other sub-themes emerged within the overall theme of the activity's effect on the students' attitudes and feelings: (1) feelings of self-efficacy in communication and/or debating science, (2) feelings of motivation to learn and participate in the activity, (3) intentions for post-activity science communication and/or debating behaviours, and (4) reactions to in-debate science communication and/or debating behaviours. The least commonly-discussed of these was the students' feelings of learning motivation, foregrounding another factor that future instructors should ensure that they are able to foster in their students. While this study is unable to provide any suggestions for how to do so, perhaps future researchers could examine potential pathways for nurturing such motivation.

The third most-discussed of these four sub-themes was the students' feelings of communication/debating self-efficacy. While some were able to confidently present and subsequently listed it in their reflections as a strong point of their performance (with some of these respondents adding on that they were able to increase their sense of self-efficacy thanks to gaining more experience with the stresses of public science communication), a (smaller) subset had instead struggled, pointing to the stress of the experience as a contributing factor for their poor performance. The reflections of this subset are further corroborated by video footage of a student whose nervousness-induced behaviours (e.g. not maintaining eye contact with the audience, forgetting what they wanted to say and being forced to read from a script, fidgeting) ended up detracting from their performance.

Consequently, they relayed having experienced a decrease in their sense of communication self-efficacy — a worrisome learning outcome considering how it may also decrease their willingness to continue along the path of being a science communicator. Accordingly, future instructors will need to ensure that their students do not feel so much stress that they suffer the same fate but still experience enough that they can see themselves as capable of handling themselves in tough science communication contexts/debates, thereby increasing their sense of self-efficacy. Perhaps the instructors could build up on their students' comfort with debating by holding low-stakes, un-assessed warm-ups/"dry runs" of the in-class debate activity beforehand.

The second most-discussed of the four sub-themes was the students' reactions to in-debate communication/debating behaviours. Of particular note is how most (i.e. 23) students had reported changing their self-perceptions of their debate performance's quality upon reviewing video footage of it. This portion of the activity allowed them to notice aspects of their performance that they may have missed and/or did not remember, thereby highlighting video reviews as a learning tool that should be kept in future iterations of this activity. In theory, this would allow the students to obtain a more balanced, objective view of how well/poorly they did.

However, there is a major limitation: as evidenced by the discrepancies between the survey reflections of three students of interest and observations of what actually happened in their debate as recorded by their respective videos, reflections/self-assessments aided by a video review may not actually be accurate. Accordingly, this study recommends future instructors to supplement their students' self-assessments with evaluations from objective third-party/external reviewers.

Returning to the four sub-themes, the most commonly-discussed of them was the students' intentions for post-activity science communication/debating behaviours. All students had reported acquiring skills and competencies that would aid them in future communication scenarios (including debates), thereby demonstrating the educational value of this activity.

Adding on to this demonstration, the remaining two common themes that arose in the students' surveys entailed (1) knowledge about general public science communication principles and (2) knowledge about debate-specific public science communication principles. All discussed principles were supported by pre-existing science communication literature, re-emphasising that this activity's learning outcomes did have academic support. With that being said, each principle had both respondents reporting high and low competency/comfortableness with it. No general outliers were apparent, aside from over half of the respondents stating that they had struggled with knowing the other side, specifically in the context of creating rebuttals. Accordingly, future instructors conducting this in-class debate activity could implement warm-up exercises that would specifically target students' competency in this aspect of debating.

Regardless, all public communication principles discussed by the 28 students are listed in **Table 5**. Accordingly, future researchers wishing to examine/quantify debate-mediated improvements in specific communication competencies and/or investigate their determinants/influences will have a research foundation to build off of (i.e. the researchers can base their competencies of interest off of this study's results as opposed to having to start from scratch).

Limitations

However, this study comes with some caveats. Firstly, as discussed in the conclusion, the results observed in the thematic analyses of the reflective survey responses may not present the full picture of what students experienced or may even have been completely incorrect, with this being based on discrepancies between the survey responses of three respondents and video recordings of their associated debate performances. With that being said, not all videos were watched. There is the possibility that the remaining 25 survey responses were faithful to what actually transpired during the debate and that the three were just outliers. Regardless, to obtain a more accurate idea of students' experiences, this study should have analyzed the videos of all debates.

Another limitation of the self-assessments/reflections was the open-ended nature of the survey questions. While doing so — as discussed by Creswell (2012) — is appropriate for exploratory studies such as this one where the range of possible responses could extend beyond (and thus expand upon) pre-existing conceptions about the topic, it also meant that students may not (and did not) organically (i.e. unprompted) bring up factors that pre-existing literature has highlighted. Such factors such as their attitudes towards public science communication as a whole or in their beliefs towards how their colleagues/classmates view various public communication/rhetorical tactics would have been interesting to analyze given how they have been linked to one's future willingness to engage with public/non-specialist audiences (Besley et al., 2018a; Besley et al., 2018b). If this study's students had reflected on changes in these factors and why they felt such ways, more conclusions and implications would come about on how instructors organizing future renditions of the in-class debate activity can take care to ensure their classes continue along the path of becoming a science communicator.

An additional major caveat concerns itself with how this debate activity was the culmination of an entire semester filled with lectures and other activities/assignments. Consequently, there was no ability to tease apart the influence of these factors apart from the debate activity itself.

Finally, this study examined a single classroom in a setting with its own unique culture, set of students, course instructor, and other characteristics. Repeating the debate activity as-is in another classroom may result in a different set of themes arising in their students' responses. After all, there is no guarantee that the way they experience the activity will be the same.

Bibliography

Abd-El-Khalick, F. (2002). Rutherford's enlarged: A content-embedded activity to teach about nature of science. *Physics Education, 37*(1), 64-68. https://doi.org/10.1088/0031-9120/37/1/309

Abdulwahed, M., & Nagy, Z.K. (2009). Applying Kolb's Experiential Learning Cycle for laboratory education. *Journal of Engineering Education*, *98*(3), 283-294. https://doi.org/10.1002/j.2168-9830.2009.tb01025.x

Addis, M. (2005). New technologies and cultural consumption — edutainment is born! *European Journal of Marketing, 39*(7/8), 729-736. https://doi.org/10.1108/03090560510601734

Ajzen, I. (1991). The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes, 50*(2), 179-211. https://doi.org/10.1016/0749-5978(91)90020-T

Akin, H., Rodgers, S., & Schultz, J.C. (2021). Science communication training as information seeking and processing: A theoretical approach to training early-career scientists. *Journal of Science Communication, 20*(5), A06. https://doi.org/10.22323/2.20050206

Ali, K.A., & Celentano, L.P. (2017). Addressing vaccine hesitancy in the "post-truth" era. *Eurohealth*, *23*(4), 16-20. https://apps.who.int/iris/handle/10665/332615

Altman, K., Yelton, B., Hart, Z., Carson, M., Schandera, L., Kelsey, R.H., Porter, D.E., & Friedman, D.B. (2020). "You gotta choose your words carefully": Findings from interviews with environmental health scientists about their research translation perceptions and training needs. *Journal of Health Communication*, *25*(5), 454-462. https://doi.org/10.1080/10810730.2020.1785060

Anderegg, W.R.L., Prall, J.W., Harold, J., & Schneider, S.H. (2010). Expert credibility in climate change. *Proceedings of the National Academy of Sciences, 107*(27), 12107-12109. https://doi.org/10.1073/pnas.1003187107

Appiah, B., Poudyal, A., Anum, D.A., Appiah, G., Wesuta, A.C., Akodwaa-Boadi, K., Ogodo, O., Nakkazi, E., Mulogo, E.M., & Odai, S.N. (2020). Challenges and facilitators of public engagement with water, sanitation, hygiene and other environmental health issues in Ghana and Uganda: Perspectives of scientists, journalists and the public. *Journal of Water, Sanitation and Hygiene for Development*, *10*(1), 16-26. https://doi.org/10.2166/washdev.2019.019

Arnsten, A., Mazure, C.M., & Sinha, R. (2012). Neural circuits responsible for conscious self-control are highly vulnerable to even mild stress. When they shut down, primal impulses go unchecked and mental paralysis sets in. *Scientific American, 306*(4), 48-53. https://doi.org/10.1038/scientificamerican0412-48

Balloffet, P., Courvoisier, F.H., & Lagier, J. (2014). From museum to amusement park: The opportunities and risks of edutainment. *International Journal of Arts Management, 16*(2), 4-18. https://www.jstor.org/stable/24587153

Bankston, A., & McDowell, G.S. (2018). Changing the culture of science communication training for junior scientists. *Journal of Microbiology & Biology Education, 19*(1), 19.1.43. https://doi.org/10.1128/jmbe.v19i1.1413

Baram-Tsabari, A., & Lewenstein, B.V. (2017). Science communication training: What are we trying to teach? *International Journal of Science Education, Part B: Communication and Public Engagement, 7*(3), 285-300. https://doi.org/10.1080/21548455.2017.1303756

Bauer, M.W., Allum, N., & Miller, S. (2007). What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. *Public Understanding of Science, 16*(1), 79-95. https://doi.org/10.1177/0963662506071287

Beason-Abmayr, B., & Wilson, J.W. (2018). Building a partnership with a campus communication center. *Journal of Microbiology & Biology Education, 19*(1). https://doi.org/10.1128/jmbe.v19i1.1495

Beck, D.L., & Srivastava, R. (1991). Perceived level and sources of stress in baccalaureate nursing students. *Journal of Nursing Education, 30*(3), 127-133.

Beebe, S.A. (1974). Eye contact: A nonverbal determinant of speaker credibility. *The Speech Teacher, 23*(1), 21-25. https://doi.org/10.1080/03634527409378052

Bennett, N., Dudo, A., Yuan, S., & Besley, J. (2019). Scientists, trainers, and the strategic communication of science. In T.P. Newman (Ed.), *Theory and best practices in science communication training* (pp. 9-31). Routledge.

Besley, J.C., Dudo, A., & Storksdieck, M. (2015). Scientists' views about communication training. *Journal of Research in Science Teaching, 52*(2), 199-220. https://doi.org/10.1002/tea.21186

Besley, J.C., Dudo, A.D., & Yuan, S. (2018a). Scientists' views about communication objectives. *Public Understanding of Science, 27*(6), 708-730. https://doi.org/10.1177/0963662517728478

Besley, J.C., Dudo, A.D., Yuan, S., & Ghannam, N.A. (2016). Qualitative interviews with science communication trainers about communication objectives and goals. *Science Communication, 38*(3), 356-381. https://doi.org/10.1177/1075547016645640

Besley, J.C., Dudo, A., Yuan, S., & Lawrence, F. (2018b). Understanding scientists' willingness to engage. *Science Communication, 40*(5), 559-590. https://doi.org/10.1177/1075547018786561

Besley, J.C., O'Hara, K., & Dudo, A. (2019). Strategic science communication as planned behavior: Understanding scientists' willingness to choose specific tactics. *PLoS ONE, 14*(10), e0224039. https://doi.org/10.1371/journal.pone.0224039

Besley, J.C., & Tanner, A.H. (2011). What science communication scholars think about training scientists to communicate. *Science Communication, 33*(2), 239-263. https://doi.org/10.1177/1075547010386972

Bickerstaff, K., Lorenzoni, I., Pigeon, N.F., Poortinga, W., & Simmons, P. (2008). Reframing nuclear power in the UK energy debate: Nuclear power, climate change mitigation and radioactive waste. *Public Understanding of Science*, *17*(2), 145-169. https://doi.org/10.1177/0963662506066719

Bodie, G.D. (2010). A racing heart, rattling knees, and ruminative thoughts: Defining, explaining, and treating public speaking anxiety. *Communication Education, 59*(1), 70-105. http://doi.org/10.1080/03634520903443849

Bray, B., France, B., & Gilbert, J.K. (2012). Identifying the essential elements of effective science communication: What do the experts say? *International Journal of Science Education*, *Part B, 2*(1), 23-41. https://doi.org/10.1080/21548455.2011.611627

Brisman, A. (2018). Representing the "invisible crime" of climate change in an age of post-truth. *Theoretical Criminology, 22*(3), 468-491. https://doi.org/10.1177/1362480618787168

Brownell, S.E., Price, J.V., & Steinman, L. (2013). Science communication to the general public: Why we need to teach undergraduate and graduate students this skill as part of their formal scientific training. *The Journal of Undergraduate Neuroscience Education*, *12*(1), E6-E10. https://www.ncbi.nlm.nih.gov/pubmed/24319399

Bucchi, M. (2008). Of deficits, deviations and dialogues: Theories of public communication of science. In M. Bucchi & B. Trench (Eds.), *Handbook of public communication of science and technology* (pp. 57-76). Routledge.

Cahill, L., Gorski, L., & Le, K. (2003). Enhanced human memory consolidation with post-learning stress: Interaction with the degree of arousal at encoding. *Learning Memory, 10*(4), 270-274. https://doi.org/10.1101/lm.62403

Carini, R.M., Kuh, G.D., & Klein, S.P. (2006). Student engagement and student learning: Testing the linkages. *Research in Higher Education, 47*(1), 1-32. https://doi.org/10.1007/s11162-005-8150-9

Carr, A.E., Grand, A., & Sullivan, M. (2017). Knowing me, knowing you. *Science Communication, 39*(6), 771-781. https://doi.org/10.1177/1075547017736891

Ceccarelli, L. (2011). Manufactured scientific controversy: Science, rhetoric, and public debate. *Rhetoric and Public Affairs, 14*(2), 195-228. https://www.jstor.org/stable/41940538

Clark, R.W., Threeton, M.D., & Ewing, J.C. (2010). The potential of experiential learning models and practices in career and technical education & career and technical teacher education. *Journal of Career and Technical Education, 25*(2), 46-62. http://doi.org/10.21061/jcte.v25i2.479

Clarkson, M.D., Houghton, J., Chen, W., & Rohde, J. (2018). Speaking about science: A student-led training program improves graduate students' skills in public communication. *Journal of Science Communication, 17*(2). https://doi.org/10.22323/2.17020205

Collins, J. (2004). Education techniques for lifelong learning: Giving a PowerPoint presentation: The art of communicating effectively. *Radiographics, 24*(4), 1185-1192. https://doi.org/10.1148/rg.244035179

Concannon, C., & Grenon, M. (2016). Researchers: Share your passion for science! *Biochemical Society Transactions, 44*(5), 1507-1515. https://doi.org/10.1042/BST20160086

Creswell, J.W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Pearson.

Cutts, F.T., Franceschi, S., Goldie, S., Castellsague, X., De Sanjose, S., Garnett, G., Edmunds, W.J., Claeys, P., Goldenthal, K.L., Harper, D.M., & Markowitz, L. (2007). Human papillomavirus and HPV vaccines: A review. *Bulletin of the World Health Organization, 85*(9), 719-726. https://doi.org/10.2471/blt.06.038414

De Backer, C.J.S., & Hudders, L. (2016). Look who's cooking. Investigating the relationship between watching educational and edutainment TV cooking shows, eating habits and everyday cooking practices among men and women in Belgium. *Appetite, 96*, 494-501. https://doi.org/10.1016/j.appet.2015.10.016

De Clippele, L., Michelotti, M., Findlay, C.R., Cartwright, A., Fang, Q., Wheatley, C., Sladen, A., Scott-Somme, K., Harding, H.R., Jackson, J., Hepburn, L.E., Giannotti, J., Carroll, G., Heidtke, N., Worrall, A.M., & De Meyer, K. (2021). The Future of Our Sea: Marine scientists and creative professionals collaborate for science communication. *Research for All, 5*(1), 134-156. https://doi.org/10.14324/RFA.05.1.11

De Vries, H., Dijkstra, M., & Kuhlman, P. (1988). Self-efficacy: The third factor besides attitude and subjective norm as a predictor of behavioural intentions. *Health Education Research, 3*(3), 273-282. https://doi.org/10.1093/her/3.3.273

Dilger, A.C., & McKeith, F.K. (2015). Training graduate students to communicate science to broad audiences. *Animal Frontiers, 5*(3), 60-63. https://doi.org/10.2527/af.2015-0036

Dror, A.A., Eisenbach, N., Taiber, S., Morozov, N.G., Mizrachi, M., Zigron, A., Srouji, S., & Sela, E. (2020). Vaccine hesitancy: The next challenge in the fight against COVID-19. *European Journal of Epidemiology, 35*, 775-779. https://doi.org/10.1007/s10654-020-00671-y

Druschke, C.G., & McGreavy, B. (2016). Why rhetoric matters for ecology. *Frontiers in Ecology and the Environment, 14*(1), 46-52. https://doi.org/10.1002/16-0113.1

Dudo, A., & Besley, J.C. (2016). Scientists' prioritization of communication objectives for public engagement. *PLoS ONE, 11*(2), e0148867. https://doi.org/10.1371/journal.pone.0148867

Dudo, A., Besley, J.C., & Yuan, S. (2021). Science communication training in North America: Preparing whom to do what with what effect? *Science Communication, 43*(1), 33-63. https://doi.org/10.1177/1075547020960138

Esmene, S., Taylor, T., & Leyshon, M. (2017). Knowledge, experience and the circus: Academic perspectives on the processes of communicating the environmental and health impacts of electric vehicles. *Local Environment, 22*(6), 651-666. https://doi.org/10.1080/13549839.2016.1250736

Fischhoff, B. (1995). Risk perception and communication unplugged: Twenty years of process. *Risk Analysis, 15*(2), 137-145. https://doi.org/10.1111/j.1539-6924.1995.tb00308.x

Fischhoff, B. (2013). The sciences of science communication. *Proceedings of the National Academy of Sciences, 110*(Supplement 3), 14033-14039. https://doi.org/10.1073/pnas.1213273110

Frewer, L., Hunt, S., Brennan, M., Kuznesof, S., Ness, M., & Ritson, C. (2003). The views of scientific experts on how the public conceptualize uncertainty. *Journal of Risk Research, 6*(1), 75-85. https://doi.org/10.1080/1366987032000047815

Gascoigne, T., & Metcalfe, J. (2017). The emergence of modern science communication in Australia. *Journal of Science Communication, 16*(3), A01. https://doi.org/10.22323/2.16030201

Green, M., & McNeese, M.N. (2007). Using edutainment software to enhance online learning. *International Journal on E-Learning, 6*(1), 5-16. https://www.learntechlib.org/primary/p/6317/

Greer, S., Alexander, H., Baldwin, T.O., Freeze, H.H., Thompson, M., Hunt, G., & Snowflack, D.R. (2018). The Art of Science Communication — A novel approach to science communication training. *Journal of Microbiology & Biology Education, 19*(1). https://doi.org/10.1128/jmbe.v19i1.1547

Gross, A.G. (1994). The roles of rhetoric in the public understanding of science. *Public Understanding of Science, 3*(1), 3-23. https://doi.org/10.1088/0963-6625/3/1/001

Grubert, E., & Cook, M. (2017). Communication science for science communication: Water management for oil and natural gas extraction. *Journal of Water Resources Planning and Management, 143*(11), 05017014. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000842

Guenther, L., & Joubert, M. (2017). Science communication as a field of research: Identifying trends, challenges and gaps by analysing research papers. *Journal of Science Communication, 16*(2), https://doi.org/10.22323/2.16020202

Haines, A., & Patz, J.A. (2004). Health effects of climate change. *Journal of the American Medical Association, 291*(1), 99-103. https://doi.org/10.1001/jama.291.1.99

Hansen, W.D., Scholl, J.P., Sorensen, A.E., Fisher, K.E., Klassen, J.A., Calle, L., Kandlikar, G.S., Kortessis, N., Kucera, D.C., Marias, D.E., Narango, D.L., O'Keeffe, K., Recart, W., Ridolfi, E., & Shea, M.E. (2018). How do we ensure the future of our discipline is vibrant? Student reflections on careers and culture of ecology. *Ecosphere, 9*(2). https://doi.org/10.1002/ecs2.2099

Hood, S., & Forey, G. (2005). Introducing a conference paper: Getting interpersonal with your audience. *Journal of English for Academic Purposes, 4*(4), 291-306. https://doi.org/10.1016/j.jeap.2005.07.003

Hofmann, S.G., Gerlach, A.L., Wender, A., & Roth, W.T. (1997). Speech disturbances and gaze behavior during public speaking in subtypes of social phobia. Journal of Anxiety Disorders, 11(6), 573-585. https://doi.org/10.1016/s0887-6185(97)00040-6

Ihlen, Ø. (2020). Science communication, strategic communication and rhetoric: The case of health authorities, vaccine hesitancy, trust and credibility. *Journal of Communication Management, 24*(3), 163-167. https://doi.org/10.1108/JCOM-03-2020-0017

Illingworth, S.M., & Roop, H.A. (2015). Developing key skills as a science communicator: Case studies of two scientist-led outreach programmes. *Geosciences, 5*(1), 2-14. https://doi.org/10.3390/geosciences5010002

Jones, M.C., & Johnston, D.W. (1997). Distress, stress and coping in first-year student nurses. *Journal of Advanced Nursing, 26*(3), 475-482. https://doi.org/10.1046/j.1365-2648.1997.t01-5-00999.x

Kahan, D.M. (2015). Climate-science communication and the measurement problem. *Political Psychology, 36*(S1), 1-43. https://doi.org/10.1111/pops.12244

Kahan, D.M., & Landrum, A.R. (2017). A tale of two vaccines — and their science communication environments. In K.H. Jamieson, D.M. Kahan, & D.A. Scheufele (Eds.), *The Oxford Handbook of the Science of Science Communication* (pp. 165-172). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190497620.013.18

Kaiseler, M., Polman, R.C.J., & Nicholls, A. (2009). Mental toughness, stress, stress appraisal, coping and coping effectiveness in sport. *Personality and Individual Differences, 47*(7), 728-733. http://doi.org/10.1016/j.paid.2009.06.012

Kappel, K., & Holmen, S.J. (2019). Why science communication, and does it work? A taxonomy of science communication aims and a survey of the empirical evidence. *Frontiers in Communication, 4*(55). https://doi.org/10.3389/fcomm.2019.00055

Klöckner, C.A. (2015). *The psychology of pro-environmental communication.* Palgrave Macmillan. https://doi.org/10.1057/9781137348326

Kolb, D.A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice Hall.

Kollmuss, A., & Agyeman, J. (2002). Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research, 8*(3), 239-260. https://doi.org/10.1080/13504620220145401

Kompella, P., Gracia, B., LeBlanc, L., Engelman, S., Kulkarni, C., Desai, N., June, V., March, S., Pattengale, S., Rodriguez-Rivera, G., Ryu, S.W., Strohkendl, I., Mandke, P., & Clark, G. (2020). Interactive youth science workshops benefit student participants and graduate student mentors. *PLoS Biol, 18*(3), e3000668. https://doi.org/10.1371/journal.pbio.3000668

Konak, A., Clark, T.K., & Nasereddin, M. (2014). Using Kobl's Experiential Learning Cycle to improve student learning in virtual computer laboratories. *Computers & Education,* 72*, 11-22.* https://doi.org/10.1016/j.compedu.2013.10.013

König, L., & Jucks, R. (2019). Hot topics in science communication: Aggressive language decreases trustworthiness and credibility in scientific debates. *Public Understanding of Science, 28*(4), 401-416. https://doi.org/10.1177/0963662519833903

Kuchel, L. (2019). Insights for designing science communication training from formal science education: Apply the mantra and be explicit. In T. Newman (Ed.), *Theory and best practices in science communication training.* Routledge. https://doi.org/10.4324/9781351069366-8

Kuh, G.D. (2001). Assessing what really matters to student learning: Inside the National Survey of Student Engagement. *Change: The Magazine of Higher Learning, 33*(3), 10-17. https://doi.org/10.1080/00091380109601795

Kuh, G.D., Cruce, T.M., Shoup, R., Kinzie, J., & Gonyea, R.M. (2008). Unmasking the effects of student engagement on first-year college grades and persistence. *The Journal of Higher Education, 79*(5), 540-563. http://www.jstor.org/stable/25144692

Lacy, C.R., Contrada, R.J., Robbins, M.L., Tannenbaum, A.K., Moreyra, A.E., Chelton, S., & Kostis, J.B. (1995). Coronary vasoconstriction induced by mental stress (simulated public speaking). *American Journal of Cardiology, 75*(7), 503-505. https://doi.org/10.1016/s0002-9149(99)80590-6

LeBlanc, V.R. (2009). The effects of acute stress on performance: Implications for health professions education. *Academic Medicine, 84*(10), S25-S33. https://doi.org/10.1097/ACM.0b013e3181b37b8f

Lin, H.-S., Hong Z.-R., & Huang, T.-C. (2012). The role of emotional factors in building public scientific literacy and engagement with science. *International Journal of Science Education, 34*(1), 25-42. http://doi.org/10.1080/09500693.2010.551430

Luisi, M.L.R., Rodgers, S., & Schultz, J.C. (2019). Experientially learning how to communicate science effectively: A case study on decoding science. *Journal of Research in Science Teaching, 56*(8), 1135-1152. https://doi.org/10.1002/tea.21554

Mackay, S.M., Tan, E.W., & Warren, D.S. (2020). Developing a new generation of scientist communicators through effective public outreach. *Communications Chemistry, 3*, 76. https://doi.org/10.1038/s42004-020-0315-0

Mayhew, M.A., & Hall, M.K. (2012). Science communication in a Café Scientifique for high school teens. *Science Communication*, *34*(4), 546-554. https://doi.org/10.1177/1075547012444790

McCartney, M., Childers, C., Baiduc, R.R., & Barnicle, K. (2018). Annotated primary literature: A professional development opportunity in science communication for graduate students and postdocs. *Journal of Microbiology & Biology Education*, *19*(1). https://doi.org/10.1128/jmbe.v19i1.1439

Mercer-Mapstone, L., & Kuchel, L. (2015). Core skills for effective science communication: A teaching resource for undergraduate science education. *International Journal of Science Education, Part B, 7*(2), 181-201. https://doi.org/10.1080/21548455.2015.1113573

Mizumachi, E., Matsuda, K., Kano, K., Kawakami, M., & Kato, K. (2011). Scientists' attitudes toward a dialogue with the public: A study using "science cafes". *Journal of Science Communication*, *10*(4). https://doi.org/10.22323/2.10040202

Morgan, M., Collins, W.B., Sparks, G.G., & Welch, J.R. (2018). Identifying relevant anti-science perceptions to improve science-based communication: The negative perceptions of science scale. *Social Sciences, 7*(4), 64. https://doi.org/10.3390/socsci7040064

Nadkarni, N.M., Weber, C.Q., Goldman, S.V., Schatz, D.L., Allen, S., & Menlove, R. (2019). Beyond the deficit model: The ambassador approach to public engagement. *BioScience, 69*(4), 305-313. https://doi.org/10.1093/biosci/biz018

Nguyen, T.T., Criss, S., Dwivedi, P., Huang, D., Keralis, J., Hsu, E., Phan, L., Ngyuyen, L.H., Yardi, I., Glymour, M.M., Allen, A.M., Chase, D.H., Gee, G.C., Ngyuyen, Q.C. (2020). Exploring U.S. shifts in anti-Asian sentiment with the emergence of COVID-19. *International Journal of Environmental Research and Public Health, 17*(19), 7032. https://doi.org/10.3390/ijerph17197032

Nisbet, M.C. (2009). Communicating climate change: Why frames matter for public engagement, *Environment: Science and Policy for Sustainable Development, 51*(2), 12-23. http://doi.org/10.3200/ENVT.51.2.12-23

O’Connell, C., McKinnon, M., & LaBouff, J. (2020). One size does not fit all: Gender implications for the design of outcomes, evaluation and assessment of science communication programs. *Journal of Science Communication, 19*(1). https://doi.org/10.22323/2.19010206

O'Keeffe, K., & Bain, R. (2018). ComSciCon-Triangle: Regional science communication training for graduate students. *Journal of Microbiology & Biology Education, 19*(1). https://doi.org/10.1128/jmbe.v19i1.1420

Oliveira, A.W., Brown, A.O., Carroll, M.L., Blenkarn, E., Austin, B., & Bretzlaff, T. (2021). Developing undergraduate student oral science communication through video reflection. *International Journal of Science Education, Part B, 11*(2), 143-154. https://doi.org/10.1080/21548455.2021.1907630

Oxford Languages. (2016, November 8). *Word of the year 2016.* https://languages.oup.com/word-of-the-year/2016/

Paolillo, J.C. (2018). The Flat Earth phenomenon on YouTube. *First Monday, 23*(12). https://doi.org/10.5210/fm.v23i12.8251

Pierce, R.L. (2013). Bridging current issues in science and society. *Biotechnology Journal, 8*(8), 875-877. https://doi.org/10.1002/biot.201200264

Purinton, E.F., & Burke, M.M. (2019). Student engagement and fun: Evidence from the field. *Business Education Innovation Journal, 11*(2), 133-140.

Raddick, M.J., Bracey, G., Gay, P.L., Lintott, C.J., Murray, P., Schawinski, K., Szalay, A.S., & Vandenberg, J. (2010). Galaxy Zoo: Exploring the motivations of citizen science volunteers. *Astronomy Education Review, 9*(1). https://doi.org/10.3847/AER2009036

Raschick, M., Maypole, D.E., & Day, P.A. (1998). Improving field education through Kolb Learning Theory. *Journal of Social Work Education, 34*(1), 31-42. https://doi.org/10.1080/10437797.1998.10778903

Reis, G., Dionne, L., & Trudel, L. (2015). Sources of anxiety and the meaning of participation in/for science fairs: A Canadian case. *Canadian Journal of Science, Mathematics and Technology Education, 15*(1), 32-50. https://doi.org/10.1080/14926156.2014.990171

Remillard, J. (2016). Community resilience through public engagement: A study of outreach and science communication in a coastal national park site. *Reflections, 16*(1), 46-56.

Riedlinger, M., Barata, G., & Schiele, A. (2019). The landscape of science communication in contemporary Canada: A focus on anglophone actors and networks. *Cultures of Science, 2*(1), 51-63. https://doi.org/10.1177/209660831900200105

Ritterfeld, U., Weber, R., Fernandes, S., & Vorderer, P. (2004). Think science! Entertainment education in interactive theaters. *Computers in Entertainment, 2*(1), 11. https://doi.org/10.1145/973801.973819

Rodgers, S., Wang, Z., Maras, M.A., Burgoyne, S., Balakrishnan, B., Stemmle, J., & Schultz, J.C. (2018). Decoding science: Development and evaluation of a science communication training program using a triangulated framework. *Science Communication, 40*(1), 3-32. https://doi.org/10.1177/1075547017747285

Rodgers, S., Wang, Z., & Schultz, J.C. (2020). A scale to measure science communication training effectiveness. *Science Communication, 42*(1), 90-111. https://doi.org/10.1177/1075547020903057

Roger, E., & Klistorner, S. (2016). BioBlitzes help science communicators engage local communities in environmental research. *Journal of Science Communication, 15*(3). https://doi.org/10.22323/2.15030206

Rudland, J.R., Golding, C., & Wilkinson, T.J. (2020). The stress paradox: How stress can be good for learning. *Medical Education, 54*(1), 40-45. https://doi.org/10.1111/medu.13830

Salmon, R.A., & Roop, H.A. (2019). Bridging the gap between science communication practice and theory: Reflecting on a decade of practitioner experience using polar outreach case studies to develop a new framework for public engagement design. *Polar Record, 55*(4), 297-310. https://doi.org/10.1017/S0032247418000608

Schiele, B., & Landry, A. (2012). The development of science communication studies in Canada. In B. Schiele, M. Claessens, & S. Shi (Eds.), *Science communication in the world: Practices, theories and trends* (pp. 33-63). Springer Netherlands. https://doi.org/10.1007/978-94-007-4279-6_3

Sharon, A.J., & Baram-Tsabari, A. (2020). The experts' perspective of "ask-an-expert": An interview-based study of online nutrition and vaccination outreach. *Public Understanding of Science, 29*(3), 252-269. https://doi.org/10.1177/0963662519899884

Simis, M.J., Hadden, H., Cacciatore, M.A., & Yeo, S. (2016). The lure of rationality: Why does the deficit model persist in science communication? *Public Understanding of Science, 25*(4), 400-414. https://doi.org/10.1177/0963662516629749

Taddicken, M., & Wolff, L. (2020). "Fake news" in science communication: Emotions and strategies of coping with dissonance online. *Media and Communication, 8*(1), 206-217. https://doi.org/10.17645/mac.v8i1.2495

Tannenbaum, M.B., Hepler, J., Zimmerman, R.S., Saul, L., Jacobs, S., Wilson, K., & Albarracín, D. (2015). Appealing to fear: A meta-analysis of fear appeal effectiveness and theories. *Psychological Bulletin, 141*(6), 1178-1204. https://doi.org/10.1037/a0039729

Tews, M.J., Jackson, K., Ramsay, C., & Michel, J.W. (2015). Fun in the college classroom: Examining its nature and relationship with student engagement. *College Teaching, 63*(1), 16-26. https://doi.org/10.1080/87567555.2014.972318

Trench, B. (2012). Vital and vulnerable: Science communication as a university subject. In B. Schiele, M. Claessens, & S. Shi (Eds.), *Science communication in the world: Practices, theories and trends* (pp. 241-257). Springer Netherlands. https://doi.org/10.1007/978-94-007-4279-6_16

Trench, B., & Miller, S. (2012). Policies and practices in supporting scientists' public communication through training. *Science and Public Policy, 39*(6), 722-731. https://doi.org/10.1093/scipol/scs090

Tulving, E., & Craik, F.I.M. (2000). *The Oxford handbook of memory*. Oxford University Press.

Woods-Townsend, K., Christodoulou, A., Rietdijk, W., Byrne, J., Griffiths, J.B., & Grace, M.M. (2016). Meet the scientist: The value of short interactions between scientists and students. *International Journal of Science Education, Part B, 6*(1), 89-113. https://doi.org/10.1080/21548455.2015.1016134

Wang, Y., Peng, H., Huang, R., Hou, Y., & Wang, J. (2008). Characteristics of distance learners: Research on relationships of learning motivation, learning strategy, self-efficacy, attribution and learning results. *Open Learning, 23*(1), 17-28. https://doi.org/10.1080/02680510701815277

Wirz, D.S. (2018). Persuasion through emotion? An experimental test of the emotion-eliciting nature of populist communication. *International Journal of Communication, 12*, 1114-1138. https://doi.org/10.5167/UZH-149959

Wynne, B. (1992). Misunderstood misunderstanding: Social identities and public uptake of science. *Public Understanding of Science, 1*, 281-304. https://doi.org/10.1088/0963-6625/1/3/004

Xu, W., & Zammit, K. (2020). Applying thematic analysis to education: A hybrid approach to interpreting data in practitioner research. *International Journal of Qualitative Methods, 19,* 1-9. https://doi.org/10.1177/1609406920918810

Yeoman, K.H., James, H.A., & Bowater, L. (2011). Development and evaluation of an undergraduate science communication module, *Bioscience Education, 17*(1), 1-16. https://doi.org/10.3108/beej.17.7

Yuan, S., Oshita, T., AbiGhannam, N., Dudo, A., Besley, J.C., & Koh, H.E. (2017). Two-way communication between scientists and the public: A view from science communication trainers in North America. *International Journal of Science Education, Part B, 7*(4), 341-355. https://doi.org/10.1080/21548455.2017.1350789

Zhang, Y. (2021). Metaphor in science communication: With special reference to Jade Rabbit of the Moon Rover. *Science Communication, 43*(6), 719-739. https://doi.org/10.1177/10755470211042857