ORIGINAL RESEARCH OPEN ACCESS

The Impact and Effectiveness of Science Communication Training in the Honours Life Sciences Program at McMaster University

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SUMMARY

Science communication (scicomm) is the practise of using a variety of techniques to explain scientific knowledge to diverse audiences (i.e, general public, other scientists, children). This is fulfilled in order to spread awareness, create enjoyment, form an opinion, and enhance ones understanding. The ineffective communication, which the public receives is often due to scientists failing to acquire formal scicomm training in their undergraduate programs. This is needed in order to accurately communicate their research to a lay audience. This study investigates scicomm training, practises, and teaching at a whole degree across various types of courses within the undergraduate Life Sciences program at McMaster university. Based on the results, there were four skills that illustrated an increase in comfort (effectively practising/performing a skill), and four skills that showed an increase in discomfort (difficulty practising/performing a skill). Upon completing a scicomm course, there were four skill sets, which indicated that students showed an increase in comfort, regarding their ability to practise them. The results of this study contribute to curriculum development by identifying overlap; furthermore, they expose gaps of knowledge within the science program. These results influence and suggest appropriate changes to the existing curriculum, course activities and assessments, promote the development of these fundamental skills for science students as they progress through their undergraduate degrees, which is required in both academia and the workplace.

ABSTRACT

Proper training in science communication (scicomm) skills are consistently falling short of requirements in higher education. This highlights the need to examine a curriculum as a whole as opposed to a course level view. This study investigates whether or not students in their current undergraduate level are comfortable with performing various scicomm skills, in addition to exploring if the dedicated scicomm courses are effectively teaching students the necessary skills. We administered a survey to students on topics regarding scicomm, and asked them to rate their level of comfort, agreement, ranking of importance, and open-ended questions. Four scicomm skills that had the greatest increase in comfort; Argumentative Writing (12%), Literature Review (15%), Public Lecture-Style Presentation (19%), and Oral Presentation (30%). Alternatively, four scicomm skills had the greatest increase in discomfort; Debate (15%), Audio (18%), Policy Communication (19%), and Public Debate (22%). Upon completion of the scicomm courses, there was an increase in comfort for; oral science communication (22%); selecting and using the appropriate written, oral, and multimedia tools (24%); communicating science in written forms (26%); and personal knowledge of written, oral, and multimedia tools (50%). A small sample size, missing data (voluntary questions), omittance of Life Sciences research seminar courses, and uncertainty if academic level implied one took the course(s) in the same year, were limitations. These findings can inform changes to the existing curriculum in order to facilitate the development of scicomm skills for science students as they progress through their undergraduate degrees.

Keywords: Science, communication, training, student, skill, program

INTRODUCTION

The field of science communication (scicomm) is a developing discipline of research and practice that is continuously evolving.[1] Science communication entails using a variety of skills to discuss scientific philosophies, knowledge, research, and critiques to a non-science audience in an accessible, engaging, and useful manner. The goals of science communication are to spread awareness, create enjoyment, develop an interest, form an opinion, and create a better understanding when one is reading.[1] It is important to describe what science communication is and its purpose, due to the interdisciplinary nature of the field and the varying definitions and opinions on it.[2] This area of academia is not meant to encourage scientists to discuss more about their work, but to make sense of their science and inform the intended audience.[1]

Communication skills are one of the largest recognized learning outcomes across multiple undergraduate programs in higher education.[3] Learning outcomes are developed to aid in course design, teaching of material, learning opportunities, and course difficulty.[4] Learning outcomes describe the knowledge, skill, and fundamentals that one should acquire upon completion of an evaluation, course, or program.[4] Informing the public on matters related to science has become increasingly difficult for graduates of science programs due to scicomm training not being explicitly mentioned as a learning outcome. The responsibility of communicating science research, breakthroughs, and discoveries to a variety of individuals with different levels of education, has been linked to science practitioners[3]. Today, there is a global push to improve scientists' abilities to communicate research, in order to avoid the spread of misinformation and poorly communicated knowledge.[3,5] Science communication has transformed how research is prioritized, practised, and governed, this includes changing policies to accurately convey scientific findings.[6]

When trying to develop a skill, training is at the core of achieving it. Communicating about any topic, especially science, is no different. Today, scientists are expected to communicate with the public to encourage informed decision making and increase science literacy.[7] The "lay public" is everyone in society, including scientists in different disciplines (non-experts).[1,7] It is a group encompassing individuals of different professions, ages, cultures, socio-economic circumstances, and levels of knowledge.[1,7] The current rise of "media science" is growing and diverse.[8] Access to traditional forms, such as the news and various social media platforms aids in the immediate spread of information. This has influenced the push for scientists to actively connect with the public and build trust.[8] It is important to understand that not all science communicators are scientists and not all scientists are meant to be science communicators. Individuals, such as reporters, bloggers, and social media content creators are able to engage in science communication.[8] But scientists will always be regarded by news reporters, government officials, and governing bodies when making bylaws and policies.[8]

The ineffectiveness of communication that the public receives is not entirely due to a lack of science literacy, but failure in scientists acquiring formal training in science communication during their undergraduate programs.[2] Scientists are trained in analytical skills, research methodologies, problem-solving, critical thinking, and scientific literature between other scientists. These skills create the foundation for an effective scientist in order to conduct and carryout exceptional research. However, these same scientists do not learn the fundamentals required in order to communicate their research to a lay audience, as their oral, interpersonal, and written communication skills are not challenged during their undergraduate years.[5] The most obvious answer to address this gap is to increase the inclusion of communication training as a mandatory or 'generic' learning outcome for science programs, Bachelor of Science (BSc), and ensuring that graduates possess the relevant skills required.[5] Currently, scientific training seems to continuously lack the inclusion of communicating information effectively among various audiences outside the academic discipline.[9] Today, the amount of literature in this discipline is scarce and the impacts of such training are not well documented. Previous studies have examined the impact of training, solely on communication practice. This presents a call for examination into current science programs, to assess the impact and effectiveness of science communication training at an undergraduate level.

The Honours Life Sciences program at McMaster University requires students to take 1 mandatory science communication course. As a student progresses through their studies, they are given the option to enrol in additional science communication courses. These higher-level courses are designed to build on the previous knowledge, which is taught to practise and gain advanced skills. Students are taught to write different forms of work, such as lay summaries, explainers, translations, commentaries, media critiques, essays, opinion editorials, manuscripts, reflections, oral presentation of thesis', and utilizing various modes of media to communicate science, such as: blogs, websites, social media, and podcasts. They further teach students to use clear language, storytelling techniques, tailoring a message, how to elicit emotion, and deciding which medium is best to reach their audience.

The focus of our thesis work is to examine the impact and effectiveness of science communication training by mapping it throughout the undergraduate Life Sciences program. Specifically, the area of interest being investigated is the comfort level of students enrolled in their current undergraduate level (level II to V), in regards to performing various science communication skills. In addition, we explored whether or not the dedicated science communication courses are effectively teaching students the skills that are necessary for success.

LITERATURE REVIEW

1. Science Communication as an Academic Discipline

In general, academic disciplines vary, and emerge due to a variety of reasons.[10] In higher education, scicomm is a new field of study and has been incorporated as a reaction to the external demand for improved communication skills.[10] A continuous topic of conversation surrounds whether scicomm's prominent emergence demands the same merit in academia as other fields, while it progresses away from just a learning component of a course, to being recognized as its own discipline.[6] The idea of engaging non-scientific individuals with science has continued to gain momentum since the 1990s, as funding bodies in science increased as they needed to understand what their investments were contributing towards.[6] Although scicomm as a discipline is new, the practise of this skill dates back to when science emerged.[6] The interdisciplinary field of scicomm incorporates a broad range of areas; science, communication, education, pedagogy, psychology, philosophy, and sociology.[1] Literature on this topic has made it apparent that recognizing scicomm as its own academic discipline has been debated since 2010.[6] The author Gascoigne and colleagues discuss that in 2010, the phrase "books on science communication" generated over 115000[3] impressions on Google.[11] The further rise in the search for scholarly articles and journals, showed that science communication was emerging and generating questions across professionals and the public about its field.[11] The rapid rise in science communication importance can been linked to the establishment of science communication courses, certificates, degrees, and programs in universities across the globe.[12] Researcher Trench and colleagues examined the publication of papers in the field of science communication.[13] The researchers found that 37 papers were published before 1995, while 42 papers were published from 1995 to 2015 alone.[13] Borchelt's analyse of publications in the field of science communication, showed that more than twice as many articles were published between 2005 and 2009, compared to 2004 and prior.[14] The journal, *Public Understanding of Science*, increased the number of issues per year from 4 to 6 in 2009.[15] In 2012, this same journal continued to increase their issues released to 8, to reflect the growth in the research being done in science and the importance of communicating its findings.[15] Popular journals, such as *Science Communication* increased their issues published each year from 4 to 6 in 2012 and the *Journal of Science Communication* reached a new high, publishing 6 issues per year in 2016.[16] This growth in issues published is attributed to the increase in the number of submissions to journals, as well as the development and prominence of the evolving field.[17]

Arguments presented suggest that scicomm in higher education is a 'skill' that you acquire through practise in courses, as opposed to an individual field of study. However, it has further been argued that the practise of formal training at a post-secondary level aids in the development of science communication as its own academic discipline.[6] Often times the interdisciplinary nature of a field of study is viewed as a strength.[6] Higher education may see this as an instability when deciding to deem it as an academic discipline due to unclear outcomes, unstable funding for the program, and the ambiguous opinions regarding who "own's" science communication.[6]

Regardless of the continued debate surrounding its status, science communication has established itself in universities as a desired skill. Upon recognizing this demand, the need for science communicators and scientists who are trained to communicate to the lay public has drastically increased.

2. Science Communication Training: The Current State

The skill 'communication' has been introduced as a learning outcome for science degrees in many countries, including Canada.[2] Recognizing that the communication of science needs to be better taught, has resulted in an increased number of courses designed to teach and train students about effective communication techniques.[2] Although this acknowledgement is a positive step in better educating early scientists, their efforts are hindered as there is little evidence to support what the core elements taught in these courses should include.[2] The absence of a student's possession of 'generic' communication skills is the result of many factors; limited opportunities in the science curriculum due to the lack of courses offered, access to available course(s), the push/encouragement for students to enrol in scicomm directed courses, a student's perception of scicomm, and the level of importance of scicomm. Science communication courses tend to be offered as elective classes and attract individuals who actively seek learning communication opportunities or have strong interests in scicomm careers.[2] The inclusion of science communication content in other science courses (non-scicomm based) is dictated and is at the discretion of the professor in charge of lecturing.[2] This typically involves traditional writing with individuals in the same field.[2] Professors encounter challenges in communicating science effectively due to their academic discipline-specific content.[2] As scientists progress through undergraduate studies to post-graduate and then doctrine, they inevitably become more specialized in their field of study. This poses a challenge as they are unable to also become experts in science communication. This calls into question a scientist's/professor's level and ability to teach a desired skill like, 'communication' to their students, as they may also find it challenging to perform science communication practises. The lack of professors possessing a proper background and knowledge in scicomm suggests a deficiency of future students obtaining these skills. Education plays an integral part in training and preparation. This provides reason to properly map the effectiveness of scicomm training throughout undergraduate BSc programs.

One key research paper has presented results giving reason to assess the effectiveness of current scicomm training across respected universities. Mercer-Mapstone and Kuchel examined which communication skills were being taught and assessed directly, indirectly or absent in undergraduate science courses across 4 research intensive universities.[3] The researchers found that 10 of the 12 core science communication skills were absent in more than 50% of assignments.[3] In these courses, 77% of all assessments administered taught less than 5 core communication skills and 22% taught 5 or more directly.[3] There was a significance difference in how openly communication skills were taught across different majors/disciplines (i.e. Physics, Chemistry, Biology, Geography, Mathematics).[3] This is a critical finding as there is a lack of explicitness and diversity in the way communication skills are being taught based on the field of science that one is enrolled in. An encouraging trend identified was that communication assignments geared towards non-scientific audiences were taught more directly than assessments targeted at scientific audiences.[3] However, the failure to develop the necessary core science communication skills challenges the ability of early scientists to be able to communicate to a non-scientific audience. For example, the critical skill of determining whether a word is considered jargon is one that was once overlooked.

Upon the examination of learning outcomes in undergraduate science programs at research intensive universities across Canada, only 2 schools highlighted and mentioned 'communication'. Specifically, McMaster and Queens University included critical analysis of literature and refined communication skills as a pillar of learning. Institutions, such as the University of Toronto, Western, Guelph, McGill, Ryerson, and Brock, do not explicitly mention the word or discuss 'communication' as a learning outcome of their science programs, the specializations offered, and highlights of the courses. These post-secondary schools emphasized their range of courses focusing on core science skills, major fields in science, and resolving key controversies or gaps of knowledge in life sciences and healthcare.

The results presented by Mercer-Mapstone and Kuchel and the lack of acknowledgement of communication skills in Canadian universities presents reason to encourage similar studies across all universities worldwide, which are known for their respected science programs.[3]

3. Scientists as Communicators: Communicating to the Public

It is no secret that science journalism is the gateway for spreading scientific material and news to the public. Until recently, scientists have failed to prioritize the communication of their research and recognizing it as a requirement of their job.[8] This has resulted in a drastic separation between the science community and the general public.[8] Leaders of the scientific community are actively pushing their colleagues to engage more frequently with the public, in order to bring awareness to modern science that can guide personal and societal decisions.[18]

Science journalists that obtained the skills necessary for sharing science information are able to make complex topics accessible to a lay audience. A challenge in science journalism is communicating research effectively, since material can become oversimplified and generalized.[7] This can result in basic information being obscured or wrongly portrayed, initiating the spread of misinformation.[7] Scientists are solely trained to publish papers and discuss findings with their peers, making it challenging for them to understand how lay audiences think and interpret.[7] Scientific findings and analyses of results often become complicated, making it challenging to communicate these facts due to discipline-specific jargon.[7] This problem often arises as scientists fear being misunderstood and presenting inaccurate information, leading to the use of specialized language.[7] A lack of scicomm training makes it difficult for a practising scientist to determine whether a common scientific word is jargon or not. A simple word, such as 'significant' can be considered jargon, as not every individual accurately understands its meaning.[7] Phrasing in writing, like 'positive correlation' may be inferred as something positive when it can actually represent a negative link between two variables.[7] The gap between what scientists believe and what the public knows and truly understands can be bridged by incorporating formal communication skills when training aspiring scientists. This will provide the quality of discourse needed between scientists and the general public.

Although some practising scientists may not acknowledge the importance of writing to a lay audience, the ability to write for a wide range of individuals becomes increasingly important with regards to continuing their research. For example, in order to obtain funding, scientists must be able to clearly communicate to peers, reviewers, and other public bodies about how their ideas are valuable and relevant to society. Scientists are an essential link between policy makers, taxpayers, stakeholders, and governments, ensuring evidence-based decision making occurs by these individuals.[9,19]

These arguments presented prove there is a shortcoming in the science communication training at universities. Although scientists are recognizing the need to engage with the public, their goals are not comparable to the knowledge needed to effectively connect and communicate with them.[18] However, this does not mean that scientists are 'bad' at communicating, rather, it implies that effective communication skills develop from practise and it is rarely natural to anyone, especially science experts.[18] Ensuring students are partaking in these practises early on in their academic careers is vital in promoting a scientifically literate society.[20]

4. Science Communication Training and the Workplace

Today, the science community has been identified as the least trained group of professionals in public communication.[21] A survey completed by various professionals, including educators, employers, and government officials, showed that communication skills were identified as an essential requirement for the workplace by STEM graduates (**S**cience, **T**echnology, **E**ngineering, and **M**athematics).[3,6] Employers in the United Kingdom, United States, and Canada found that the training received by graduates does not reflect the reality of the modern-day workplace requirements needed to be successful.[3] Every year, a set of learning outcomes are established that act as a baseline for acquiring knowledge, helping to guide curriculum development, and promote graduate employability.[3] The reservations expressed by workplace professionals calls into question the science communication training in undergraduate programs. This demonstrates that there is a discrepancy between what universities say science graduates should be able to do and what they actually learned throughout their program.[3] There are various complaints from journalists, industries, laboratory researchers, government officials, and the public stating that scientists are not equipped with the proper communication skills needed to convey information effectively to non-experts.[3] According to McKinnon and Bryant, graduates of STEM programs who have completed science communication training and demonstrate the skills, are perceived as more valuable to future employers.[6] This illustrates that it is imperative to improve communication training in higher education to ensure graduates of a science program have a solid foundation of relevant skills for employability.

5. The Consequences of Inadequate Scicomm Training and Practise

Today, the COVID-19 pandemic has proven the importance of science communication in an age of misinformation, as new knowledge is abundant, evolving, and controversial.[22] For example, the misinformation of science and the lack of proper public communication surrounding the pandemic can hinder population health and protocol by leading to negative outcomes.[22] A lesson that has become clear during this pandemic is the improper announcing of information to the public, which makes it a challenge to counter misinformation, leading to confusion.[22] This results in public hesitation stemming from their inability to distinguish and understand the information presented to them.[22] The continued outbreaks, the uncertainty in receiving the vaccine, and the controversy over wearing a face mask, are unfortunate examples of how disorganized science communication can confuse non-scientific audiences.[22] This leads to distrust of scientists and scientific evidence, and casts doubt about the justification for health protocols and alterations in personal behaviour as new information surfaces.[22] During such major events, scientists are responsible for communicating newly emerging science with the public to ease their fears, help them make informed decisions, and encourage engagement.[20]

Policy-makers reference scientific research heavily when designing laws, as well as prior to passing legislation. When science is communicated ineffectively, flawed or biased bills and policies can be passed, affecting the lives of everyone involved.[23] Often times, new fads, trends, and conspiracies emerge, causing research to become quickly diluted with fiction and inaccuracies. The inadequate communication of proper scientific information leaves many areas associated with a negative connotation, such as climate change.[23] Numerous amounts of scientific evidence are presented each day, often times contradicting one another and making opposing claims about the reality and seriousness of an issue.[23] Upon reading the information, skepticism enters the public's perception of scientists and the entirety of the science field, followed by distrust.[23] Without the proper presentation of science and the failure to swiftly clarify statements, the consequences of these actions will begin to appear altering our way of life.[23]

When engaging with the public, scientists need to be ready to answer difficult questions regarding their research and communicate any uncertainties.[8] Engagement with the public is vital in increasing the influence of their research, forming and building trust, and enabling open conversation.[8] This allows for the public to ask questions surrounding the science and importance of their research, rather than asking questions about what they are discussing.[8] Although there is limited evidence, scientists who have formed a strong connection with the public have had their research papers cited more often by the public and other scientists than researchers who lacked that connection.[8] This aids in spreading accurate science, which is the result of proper science communication.

Study Motive

There remain gaps in the current state of science communication training and little consensus on how it should be conveyed. Undergraduate students continue to receive poor formal training in the communication of scientific theories. In this area of academia and pedagogy, there is a lack of research examining the communication of science skills at a whole degree level. A significant portion of research on science communication skills focuses on teaching practises only at a microlevel, such as an individual course or a single assessment. Evidence surrounding how current students are experiencing the teaching and absorption of knowledge of these skills also remains scarce. These gaps prove that there is a demand to further investigate scicomm training, practises, and teaching at a whole degree across various types of courses. Such exploration would contribute to curriculum development by providing insight into how current science students are experiencing the teaching and learning of communication skills throughout their degree. Using these results can influence and provide the appropriate needed changes to the existing curriculum and activities and assessments, to facilitate the scaffold and development of these skills for science students as they progress through their undergraduate degrees.

Study Objective

The focus of this study is to examine the impact and effectiveness of science communication training. This is to be accomplished by mapping it throughout the undergraduate Life Sciences program at McMaster University. Conducting this study will provide an evidence-based record of the comfortability of undergraduate science students with regards to practising various communication skills. Specifically, we pose the research question: Are students at their current undergraduate level (II to V) comfortable with performing various science communication skills? Additionally, we explored a secondary area of research by posing the question: Do dedicated science communication courses effectively teach (train) students the skills necessary to succeed in academia and the workplace?

To investigate this, we administered a survey that presented students with a variety of topics regarding science communication and asked them to rate their level of comfort, agreement with statements, and open-ended questions to express their opinions.

METHODS AND MATERIALS

Ethics approval for this study was granted by McMaster University's Research Ethics Board (Approval Number: 4985).

Survey Administration

A survey was advertised on McMasters' learning management system, Avenue to Learn, and was open to all Honours Life Sciences students during the Winter 2021 academic term. The survey was administered by Dr. X and Dr. X from the Faculty of Science and posted on Avenue to Learn on April 15th, 2021 and remained available until May 24th, 2021. Completion of the survey was anonymous and voluntary; however, a $100 Amazon gift card was an incentive advertised to participants and awarded to two respondents randomly selected by an individual independent of the research team.

In order to be eligible, participants must have been enrolled in the Honours Life Sciences program (level II to V) and completed or were enrolled in a variety of courses during the 2020-2021 academic year. These courses included: *Level II*: LIFESCI 2AA3: Introduction to Topics in Life Sciences and SCICOMM 2A03: Foundations in Science Communication; *Level III*: ENVSOCTY 3UW3: Cities of the Developing World, HISTORY 3CH3: Catastrophic History: Natural & Technological Disasters, HLTHAGE 3D03: Perspectives on Disability, Chronic Illness and Aging, HLTHAGE 3N03: Aging and Mental Health, LIFESCI 3AA3: Human Pathophysiology, LIFESCI 3BB3: Neurobiology of Disease, LIFESCI 3E03: Reproductive Endocrinology, LIFESCI 3G03: Introduction to Epidemiology, LIFESCI 3M03: Cellular Dynamics, LIFESCI 3P03: Science Communication in Life Sciences, LIFESCI 3Q03: Global Human Health and Disease, LIFESCI 3RC3: Radioisotopes in Medicine; *Level IV*: LIFESCI 4J03: Science Communication in the Media and LIFESCI 4E03: Science & Storytelling.

Survey Content

The survey contained a total of 28 questions and was administered using the Lime Survey software. The survey asked questions on a student's perception of science communication, its importance, their interest in the discipline, how well prepared they were to complete certain courses based on the course prerequisites, how comfortable they were with performing science communication skills (i.e. writing to a non-scientific audience, designing an infographic, etc.), engagement, and future career opportunities in science communication. All questions presented in the survey were optional, unless otherwise indicated that an answer was necessary. The mandatory question asked by this survey was which courses the participant have taken, have not taken, were currently enrolled in, and which ones were taken prior to Fall 2020; in addition to answering what year they were currently in at the time of the survey (Level II to Level V). Level II acts as the 'introduction of communication skills' since science communication courses are offered beginning in second year of the Honours Life Sciences program to meet program and course requirements in upper year courses.

The survey presented participants with Likert Scale responses to the questions including: numerical ranking of 1-5, strongly disagree to strongly agree, very high to very low, very comfortable to very uncomfortable. It also used open-ended responses for participants to discuss their opinions and thoughts, yes/no/unsure, and multi-select options.

The survey was completed by 95 students, specifically 26, 41, 22, and 6, from levels II, III, IV, V respectively. Due to the small sample size in level 5, the responses from that academic year were combined with level 4 for a total of 28 responses. This new value was used when calculating percentages for the results of the primary research question.

Data analysis

Microsoft Excel was used to gather, analyze, and visualize the data by designing the graphs presented in the results section. The function "COUNTIF" was used to calculate the number of responses for each individual question and by academic year, in addition to the "SUM" function when calculating the percentage of each response to the applicable question.

For the context of this study, the word "Comfortable/Comfort" is a direct indication of one's ability to practise/perform the skill in question.

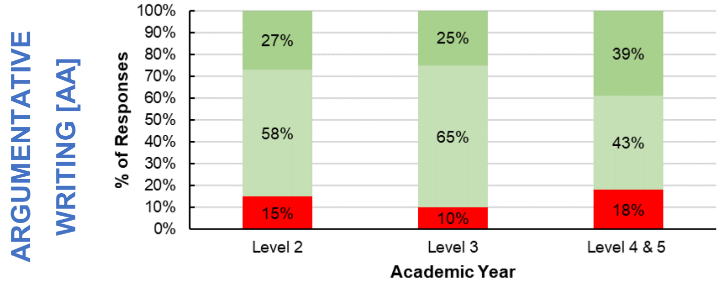
RESULTS

As stated in the figure captions presented in Figure 1 below, the abbreviation [AA] denotes Academic Audiences (i.e. other university students in a formal setting, faculty members, other researchers, or subject experts), and [NAA] denotes Non-Academic Audiences (i.e. general adults, children, community members, policy makers). As seen in the x-axis of Figure 2 below, each letter (i.e. A, B, C, etc.) indicates a specific course objective relevant to all the dedicated science communication courses presented (LIFESCI 2AA3, SCICOMM 2A03, LIFESCI 3P03) (refer to Table I for an explanation of all alphabetical letters and the applicable course objectives). As seen on the graphs, all findings were converted into a percentage and rounded to the nearest whole number for easier comprehension.

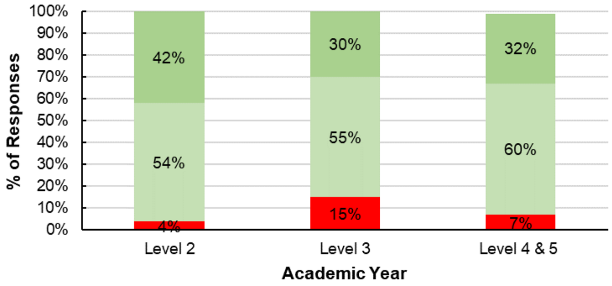
Primary Research Question: *Are students at their current undergraduate level (II to V) comfortable with performing various science communication skills?*

As depicted in Figure 1, the communication skills *Literature Review [AA]* (15% increase in comfort and a 1% decrease in discomfort), *Research Proposal [AA]* (6% in comfort and a 17% decrease in discomfort), *Oral Presentation [AA]* (30% increase in comfort and 16% decrease in discomfort), *Video [NAA]* (1% increase in comfort and a 16% decrease in discomfort), and *Public Lecture-Style Presentation [NAA]* (19% increase in comfort and a 6% decrease in comfort), all illustrated a simultaneous increase in comfort and decrease in discomfort. Therefore, this pattern indicates that dedicated science communication courses are teaching these applicable skills and a student's ability to perform (practise) them is improving. The skills *Argumentative Writing [AA]* (12% increase in comfort) and *Research Paper [AA]* (15% increase in comfort), although showed a minor increase in discomfort (less than 10%), demonstrated a considerable increase in a students' comfort level with performing the applicable skills.

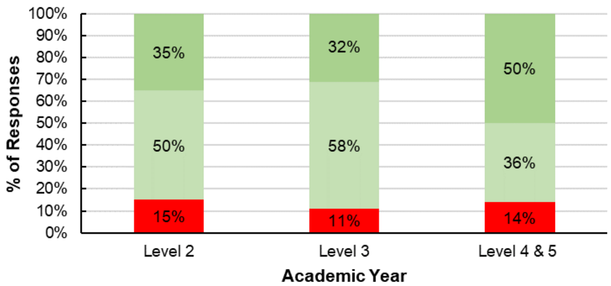
Moreover, as shown in Figure 1, the communication skills *Debate [AA]* (22% increase in discomfort), *Graphic Design [NAA]* (7% increase in discomfort), *Audio [NAA]* (18% increase in discomfort), Policy Communication (19% increase in discomfort), all illustrated a substantial increase in a students' discomfort level with performing the applicable skills. Although these skills also showed a minor increase in comfort levels, the considerable increase in discomfort over academic years indicates a gap in skill practise and teaching. As seen in Figure 1, the other applicable skills, such as *Argumentative Writing [NAA]*, *Research Poster [AA]*, *Popular Science Writing [NAA]*, *Outreach Activities [NAA]*, and *Media Interview [NAA]*, all illustrated a simultaneous minor increase and/or decrease in comfort/discomfort levels (less than/equal to 10%).



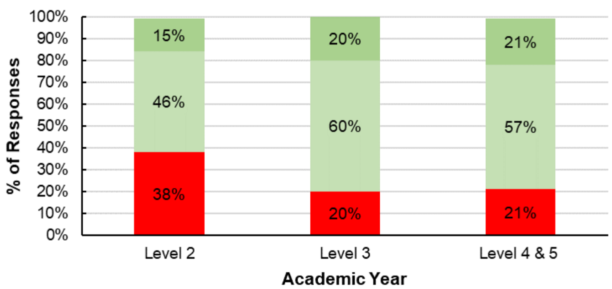
ARGUMENTATIVE WRITING [NAA]



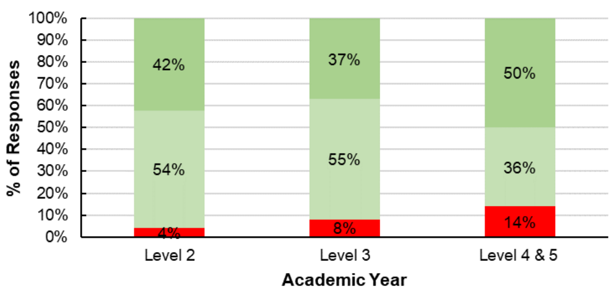
LITEARTURE REVIEW [AA]



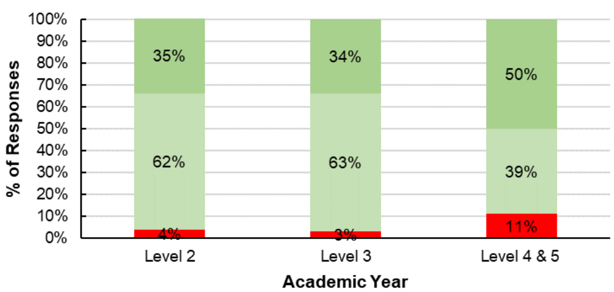
RESEARCH PROPOSAL [AA]



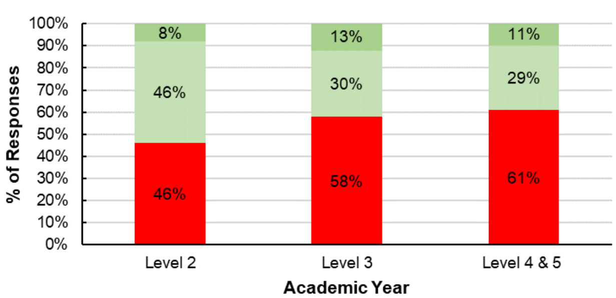
RESEARCH POSTER [AA]



RESEARCH PAPER [AA]

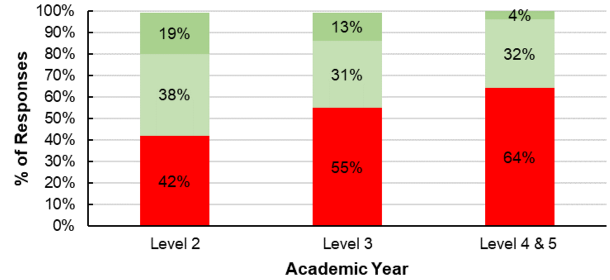


DEBATE [AA]

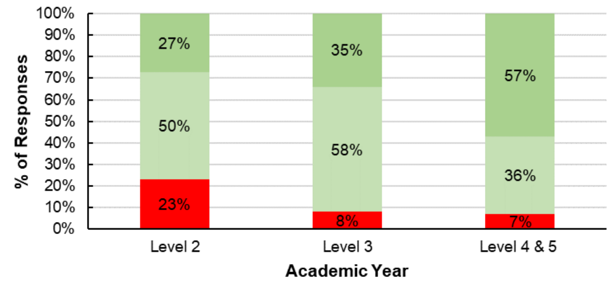


■ Not comfortable ■ Comfortable ■ Very comfortable

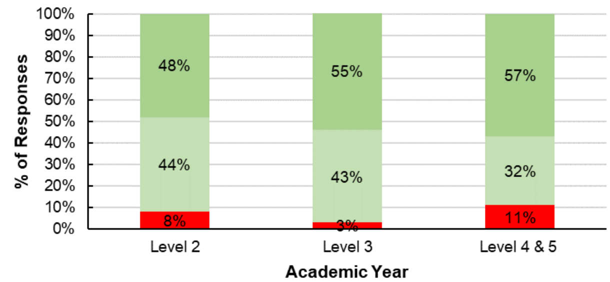
PUBLIC DEBATE [AA]



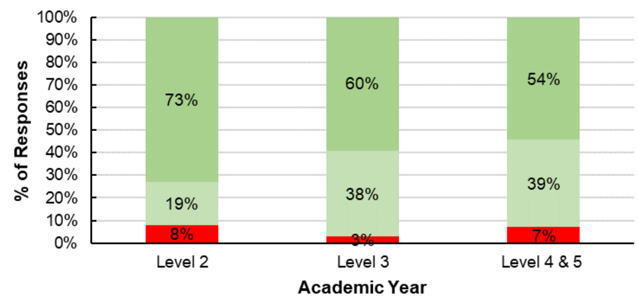
ORAL PRESENTATION [AA]



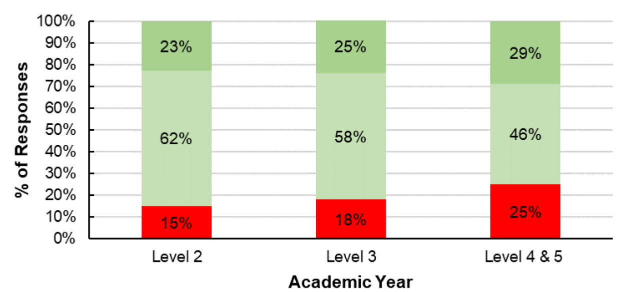
POPULAR SCIENCE WRITING [NAA]



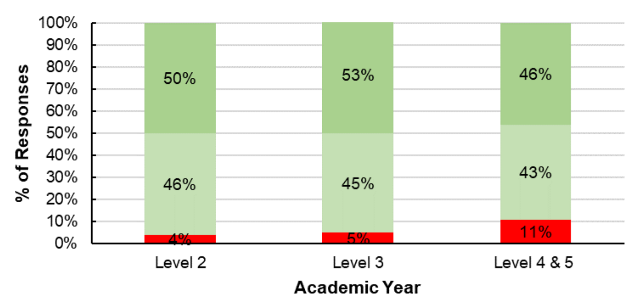
SOCIAL MEDIA POSTS [NAA]



OUTREACH ACTIVI-TIES [NAA]



GRAPHIC DESIGN [NAA]



■ Not comfortable ■ Comfortable ■ Very comfortable

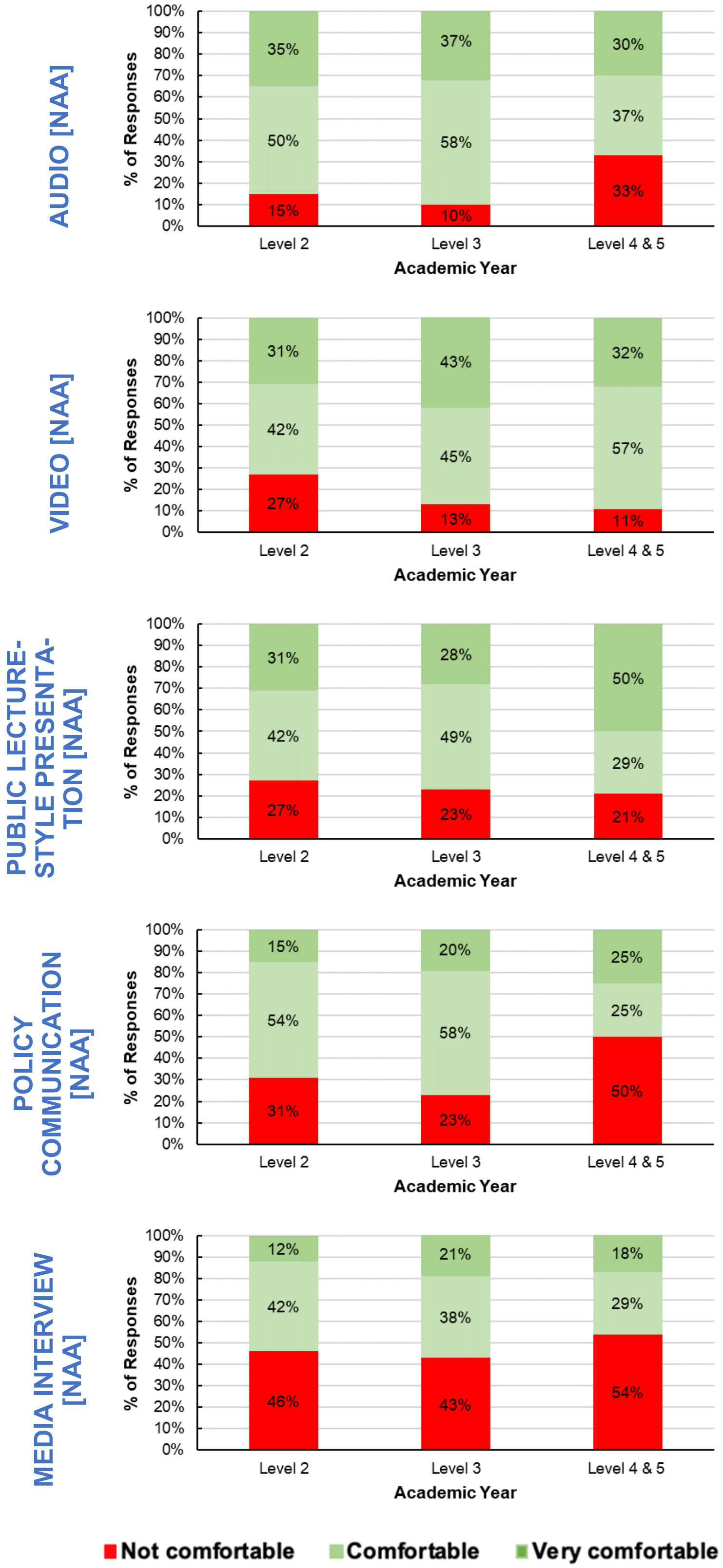


Figure 1. All responses of undergraduate Honours Life Sciences students by academic year (Levels II to V) (n=95). This figure depicts various types of science communication skills and the level of student comfort assessed by academic year; Level II (n=26), Level III (n=41), and Level IV & V (n=28). Due to the small sample size in Level V (n= 6), responses from Level V were combined with Level IV. [AA] denotes Academic Audiences and [NAA] indicates Non-Academic Audiences.

Table 1. Science Communication Objectives for LIFESCI 2AA3, SCICOMM 2A03, and LIFESCI 3P03. This table provides an explanation to each alphabetical letter presented on the X-axis as depicted in Figure 2.

Letter on Graph	Science Communication Course Objective
A	The assessment of communication skills (i.e. task, rubric, feedback etc.) appropriately aligned with what I was taught in the course.
B	I feel more comfortable communicating science topics through writing due to this course.
C	I feel more comfortable orally communicating science topics due to this course.
D	I feel more comfortable visually communicating science topics due to this course.
E	I feel more comfortable understanding and dissecting primary research papers due to this course.
F	I feel more comfortable gathering and synthesize research due to this course.
G	I feel more comfortable selecting and using appropriate written, oral, or multimedia tools due to this course.
H	I am more interested in science communication due to this course.
I	I have a deeper understanding of science communicating due to this course.
J	My knowledge of written, oral, and multimedia TOOLS has improved as a result of this course.
K	My ability to communicate science to NON-ACADEMIC AUDIENCES has improved as a result of this course.
L	My ability to communicate science to ACADEMIC AUDIENCES has improved as a result of this course.
M	My ability to gather and synthesize research has improved as a result of this course.
N	My ability to read, understand, and dissect primary research papers has improved as a result of this course.

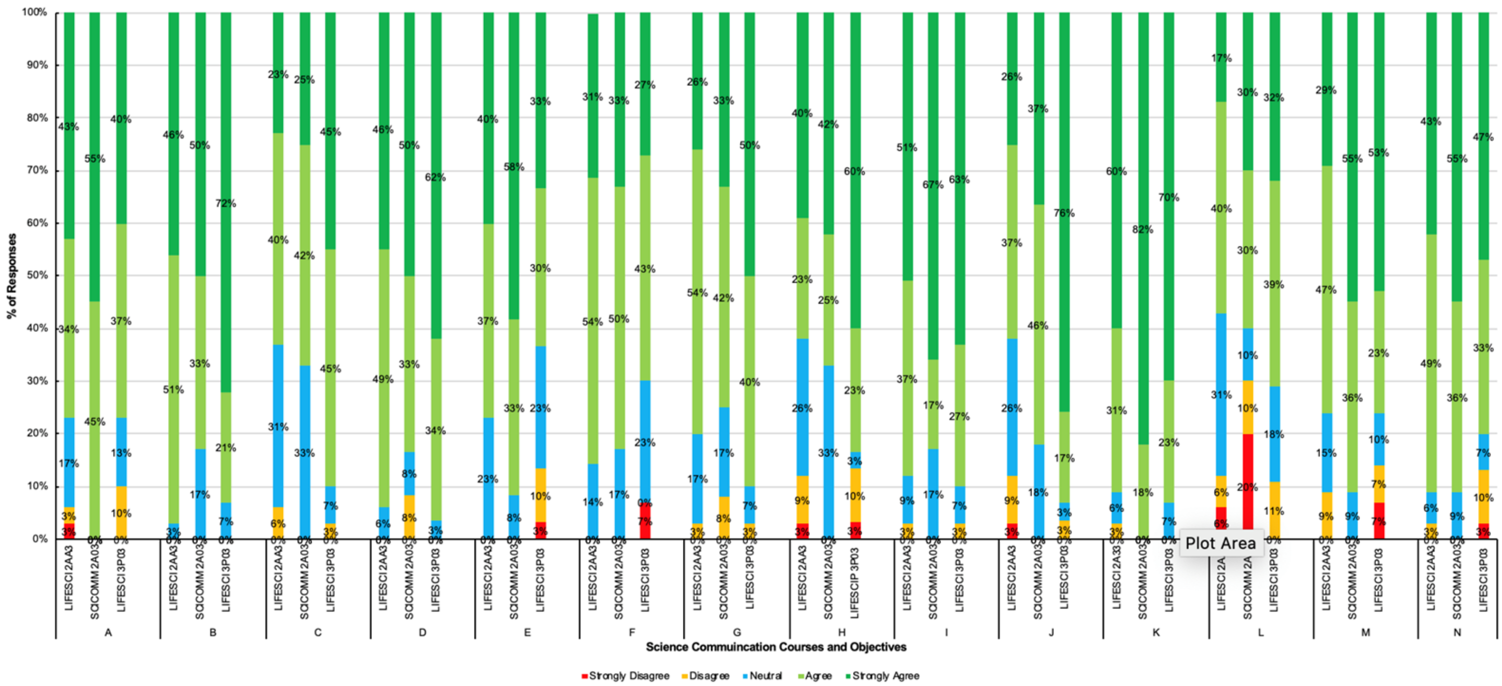


Figure 2. Science Communication Courses and Course Objectives. This figure depicts the course objectives and students' responses (in percentages) with regards to their agreement in obtaining those outcomes as a result of the applicable course (refer to Table I on page 24 for explanation of all alphabetical letters and the applicable course objectives). All responses (n=75): LIFESCI 2AA3 (n=35), SCICOMM 2A03 (n=11), and LIFESCI 3P03 (n=30). Courses LIFESCI 4J03 and LIFESCI 4E03 were omitted from the analysis due to their small sample size (n=4 and n=2, respectively).

Secondary Research Question: Do dedicated science communication courses effectively teach students the skills necessary to succeed in academia and the workplace?

As exhibited in Figure 2, the letters *B* (I feel more comfortable communicating science topics through writing due to this course), *C* (I feel more comfortable orally communicating science topics due to this course), *D* (I feel more comfortable visually communicating science topics due to this course), *F* (I feel more comfortable gathering and synthesize research due to this course), *H* (I am more interested in science communication due to this course), *J* (My knowledge of written, oral, and multimedia TOOLS has improved as a result of this course), and *L* (My ability to communicate science to ACADEMIC AUDIENCES has improved as a result of this course) all illustrated a substantial increase in agreement (shift from strongly disagree to strongly agree) upon completing the applicable science communication courses (LIFESCI 2AA3, SCICOMM 2A03, and LIFESCI 3P03). Respectively, letters *B*, *C*, *D*, *G*, *H*, *J*, and *L* had a 26%, 22%, 16%, 24%, 20%, 50%, and 15% increase in students' comfort levels. Furthermore, the increase in agreement with regards to letter J validates the substantial increase in *Oral Presentation [AA]* skills found when analyzing the data for the primary research question. This growth demonstrates that students are gaining skills (and comfort) as they progress through their undergraduate degree and complete higher level science communication courses.

Furthermore, as seen in Figure 2, letters *A* (The assessment of communication skills appropriately aligned with what I was taught in the course), *E* (I feel more comfortable understanding and dissecting primary research papers due to this course), *F* (I feel more comfortable gathering and synthesize research due to this course), *I* (I have a deeper understanding of science communication due to this course), *K* (My ability to communicate science to NON-ACADEMIC AUDIENCES has improved as a result of this course), *M* (My ability to gather and synthesize research has improved as a result of this course), and *N* (My ability to read, understand, and dissect primary research papers has improved as a result of this course), all demonstrated an increase in agreement from LIFESCI 2AA3 to SCICOMM 2A03, but showed a decrease between SCICOMM 2A03 and LIFESCI 3P03. Specifically, letters *A*, *E*, *F*, *I*, *K*, *M*, and *N* had a respective decrease of 15%, 25%, 6%, 4%, 12%, 2%, and 9% in students' comfort levels.

DISCUSSION

Science students are intended beneficiaries of an undergraduate science program. Their perception on the view of the discipline, understanding, and ability to perform communication skills across a BSc program provides valuable insight into the teaching of these fundamental skills. The academic curriculum is a conduit for the delivery of relevant and required skills that should remain constant regardless of discipline or its specific content. This is particularly relevant in the current state of placing increasing emphasis on the development of generic and commonly taught skills that are often not course-specific. Regardless of this necessary increase in skill-teaching, the skill communication and its various forms (i.e. written, oral, graphic) seem to be consistently falling short of requirements, specifically in BSc programs.

This study provides insight into the comfort level of undergraduate science students within the Honours Life Sciences program (Levels II to V) when performing science communication skills in the present, as well as after completing various Scicomm courses. Research in this area is limited. This study provides a broad yet commendable set of student perspectives and highlights an area of the existing curriculum that requires future focus. Additionally, this study raises awareness on other relevant areas in the same matter requiring further investigation/justification to current results. The literature review revealed that there are communication skills or elements cited that consistently align across the fields of science, communication, education, and science communication that are following short of requirements. This was further validated by the supporting results obtained from this study, revealing that certain science communication skills, such as *Debate*, *Public Debate*, *Graphic Design*, *Audio Tools*, and *Policy Communication* consistently showed an increase in discomfort as one progressed through their undergraduate degree in the Honours Life Sciences program at McMaster University. This increase may be attributed to dedicated Scicomm courses either minimally or not explicitly teaching these fundamental skills. Therefore, students' ability to regularly practise them is limited or impossible, which may be contributing to the rise in student discomfort. Although these same skills showed a minor increase in comfort levels, the considerable increase in discomfort over academic years indicates a gap in skill practise and teaching. The skills of Debating, Graphic Design, Audio Tools, and Policy Communication directly contribute to the modern notion of science communication as a two-way interaction in the process of sharing information and perspectives, and represents the recent shift in science communication theory from focusing on public understanding of science to public engagement with science.[24] Students struggle with making science engaging to others while presenting and transferring information in a way that encourages others to like science, due to the ambiguity around the word "engagement" and how best to formulate an argument or opinion.[2] It is possible that the increase in discomfort levels from a student's perspective could be reflective of some experts in science courses struggling to teach engagement skills in undergraduate courses.[2] As discovered in the primary research question, there was an increase in a student's comfort level with regards to oral presentation and written forms of science. This increase in comfort level may be attributed to Scicomm courses regularly teaching these skills which allows students to practice and familiarize themselves with them. Moreover, the findings obtained from the primary research question, in addition to the increase in a student's personal knowledge of written, oral, and multimedia tools after completing dedicated Scicomm courses, represents consistent teaching practises. These two research questions demonstrated a similar increase in parallel skills, indicating that they have been the central focus to effective science communication as well as being the most relevant in teaching science students how to communicate with different audiences. Although there are numerous other Scicomm skills that a science student must acquire, I believe it is important to mention that teaching these particular fundamentals at a minimum introduces the most essential aspects of science communication skills to students.

The implication of these findings is that while course objectives make the "what" clear, such as "After completing this course, students will be able to…" in syllabuses, we are overlooking the "how" process of actually practising the skills (i.e., applicable/relevant assessments to test student knowledge). Examining the "how" aspect is required for adequate development and transferal of such integral skills needed in academia and the workplace.[3] This study found differences in skills across academic levels, which provides evidence that there is little consistency across other BSc programs at McMaster University and other academic institutions regarding the way communication skills are being taught (each year) and assessed.[3] An ongoing debate exists over where to teach communication skills in science degrees and whether it should be with the addition of a dedicated course to teach a single or subset of similar skills, or to integrate them into existing courses instead. This challenges professors' abilities to effectively teach all core science communication skills.[2] A new course approach offers a student the ability to adequately obtain greater knowledge of a certain or relevant subset of skills. Integration into multiple current courses across a program allows a student to have multiple opportunities to practise and develop skills over time, which has been shown to be more effective in developing complex learning outcomes such as communication.[2] However, an integration approach can lead to the lack of communication skills, due to the amount of other necessary content already encompassing the course, such as theory, could limit the amount of Scicomm skills being taught and the ability to practise them. Therefore, research has shown that the inclusion of core communication skills in undergraduate science courses are limited and in general, this key skill is not being taught explicitly or in a cumulative manner.[3]

Knight argued that curricula with which communication skills are taught should support the progressive development of skills over time as a result of coherent, outcome-aligned, curriculum planning.[25] This argument validates the findings of the second research question, which demonstrated an increase in a student's comfort level and personal knowledge level to be able to select, use, and explain science with various communication tools and styles as a result of course curriculum and learning outcomes upon completion of the class. Therefore, a continuous and particular focus should be on consistent levels of inclusion and assessment of communication skills in an effort to make those skills more clearly visible to students to comfort in all learning outcomes and skills.

An implication of this study is that it attempted to assess a critical aspect at the whole degree level, as opposed to a course level or single assessment view (individual skill), which has been the traditional route of research in this field. This endeavour was an attempt to truly represent overlap and gaps across the BSc program with regards to science communication skills. The educational implication of the study is potentially important for university professors and science educators to enable a more holistic view of science learning, the best way to communicate the science they teach, and how students should communicate science.

Limitations, Recommendations, Next Steps, and Future Research

The most significant limitation impeding our ability to obtain more concrete results is the small sample size of the study (n=95), which hindered a complete and truly accurate representation of the Honours Life Sciences program. When attempting to answer the primary research question, response for Levels IV (n=22) and V (n=6) were combined due to small sample sizes. Since the nature of the survey did not require participants to answer every single question, data was limited regarding particular questions. This may have skewed our results. For future reference, researchers should hold all questions mandatory for students to answer in order to obtain more applicable data. Students currently enrolled in Levels IV and V of the Honours Life Sciences program have the option to complete lower level (SCICOMM 2A03) as well as upper year (LIFESCI 3P03) Scicomm courses. Thus, students in Levels IV and V are better equipped to accurately complete assignments within the course, possibly reflecting greater results on the comfort level scale. With regards to the secondary research question, LIFESCI 4J03 and LIFESCI 4E03 were omitted from analysis due to the small sample size (n=4 and n=2 respectively), which limited anaccurate representation of student comfort throughout the entire Honours Life Sciences program and dedicated Scicomm courses. The current survey hindered an accurate representation of participant responses, particularly comfort level, due to the restricted options to select from (Not comfortable, Comfortable, Very comfortable). In the future, using a new measure, such as a Likert Scale (a numerical scale from 0-10) might improve the specificity of student's comfort level and allow for a greater representation (variability) of the results. To more clearly define a student's comfort level at their current academic year, designing new questions (i.e., Completed LIFESCI 2AA3, Completed LIFESCI 3P03, Completed LIFESCI 4J03, etc.), and incorporating follow-up questions specific to each science communication course would ensure accurate comparison of a student's comfort level as either being "greater than" or "lesser than" for specific skills to previous courses.

Regarding future implications, the results in this study validate the need to incorporate more science communication courses across the Life Sciences curriculum, reducing discourse between science students and their ability to communicate information. Research seminar courses are limited by the capacity of students able to enroll in these classes. Therefore, not all students in their senior year of the program will be completing a higher-level Scicomm course. Similarly, not all students will be able to enroll in elective Scicomm courses due to student capacity, and might not have the desire to take these courses beyond their required class (LIFESCI 2AA3), which briefly introduces some skills. Designing science communication courses that are tailored to one area of expertise (i.e. outreach activities) or particularly an area where students demonstrated a higher discomfort (i.e. debate, policy communication, media interviews, public lecture-style presentations, etc.) would ensure that students are gaining the communication skills necessary in academia and the workplace.

A new area of research would be to look at all disciplines of sciences (i.e. biology, chemistry, psychology, mathematics) to measure the level of science communication skills one possesses. We strongly believe each science course, regardless of the discipline (i.e. physics, biochemistry, astronomy) should include an assignment dedicated to writing towards a lay audience. A student will typically direct most of their attention to the required courses in their program or major. However, in general, elective courses do not receive the same level of effort as program-specific courses.This results in a lack of assertiveness to actively learn the content in elective courses. Often times, science communication courses are offered as electives, which does not motivate students to enrol in them as they tend to place moderate or limited importance on Scicomm skills.[26,27] Therefore, we strongly suggest mandatory enrollment for science students in science communication courses for each academic level of undergraduate study. This would ensure that they are developing these fundamentals throughout the entirety of their programs. Within all science programs, Scicomm courses should be required rather than electives, as a significant portion of literature on this topic concludes that students in undergraduate BSc programs fail to acquire science communication skills.

CONCLUSION

This study paints a picture how undergraduate science students perceive the development of communication skills across year levels and over the course of their degree. Improvement is necessary in current teaching practises and course design in BSc programs to equip graduates with the proficiency in a diverse range of communication skills. Building these fundamentals are a challenging undertaking involving the restriction of discipline-specific jargon, effective engagement with the target audience, and extensive practise. Higher education must focus on developing these skills in courses that incorporate a balance of knowledge through scientific content, research training, and the ability to effectively communicate to form well-rounded, aspiring science graduates. This study found that a students' ability to perform various science communication skills varied in their level of comfort as there was both an increase in "comfort" and "discomfort", which could be attributed to the explicitness of the dedicated science communication course learning objectives to teach those skills (i.e. debate). However, completion of the dedicated science communication courses did indicate both a moderate and substantial increase in students' comfort levels and personal knowledge of communication tools. Although more research must be conducted using a larger sample size and examining higher level science communication courses, these findings must be incorporated into the design of existing curriculums in order to facilitate an improvement in course structure (teaching), learning objectives, and assessment(s).

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