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Exploring the YouTube science communication gender gap: A sentiment analysis

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Abstract

YouTube has become the second most popular web search engine (see Alexa.com) and the primary website for individuals and organisations to freely distribute video content. Popularity statistics indicate that Science, Technology, Engineering and Mathematics–related content is of significant interest to YouTube audiences, yet analysis of the 391 most popular science, engineering and mathematics–themed channels reveals a conspicuous absence of female communicators, with the hosts of just 32 of these channels presenting as female. To help understand potential causes of this gap, analysis was conducted on popularity indicators and audience sentiments of 450 videos from 90 Science, Technology, Engineering and Mathematics–related channels. Female hosted channels were found to accumulate more comments per view, and significantly higher proportions of appearance, hostile, critical/negative and sexist/sexual commentary.

Keywords

gender gap, popularising science, science communication, sentiment analysis, YouTube, women in science, women in Science, Technology, Engineering and Mathematics

1. Introduction

Despite decades of campaigning and equal opportunity initiatives, women working in Science, Technology, Engineering and Mathematics (STEM) fields continue to experience marginalisation and structural biases: winning fewer awards, attaining lower salaries, facing lower chances of being hired, being cited less, and winning fewer – and lower value – grants than their male counterparts (Huge et al., 2013; Luntz, 2011; Zakaib, 2011). Such discrepancies are the result of a complex range of social, cultural and structural influences and biases (Luntz, 2011), but critical among these are media representation and rolemodeling. Media representation of scientists and STEM careers in ways supposedly incongrous with stereotyped images of femininity have been

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shown to result in a masculinised perception of STEM among girls, and a devaluing of their own potential ability to pursue science (Applegate et al., 2010; Steinke, 1999).

While traditional media bear significant responsibility for this representational discrepancy (Kitzinger et al., 2008), representations of STEM disciplines and STEM workers in online media also serve to constrain the career and educational choices of women and girls (Mendick and Moreau, 2013). Indeed, despite the ease, access and popularity of modern online media, the persistent gender disparity in broader representation of science and scientists also appears to affect online STEM communicators. In YouTube, for example, female presences are visibly rare amid the most popular videos and channels overall (Tucker-McLaughlin, 2013) – rarer, indeed, than in traditional media (Kietzmann et al., 2011; McMillan and Wotanis, 2014). This discrepancy is particularly worrying in a world where online media consumption among young people – the STEM workforce of the future – now outpaces traditional media consumption (Deloitte, 2016). As YouTube science communicator Joanne Manaster has noted, 'If young people do not see women articulating science, the impression will be that women don't do science' (Manaster, 2013, para. 12).

This presents a critical question: if we are to address gender disparities in STEM more broadly, then we need to understand more about gender disparities in key online media. This study examines the presence of and reaction to women on YouTube in particular.

This study aims to achieve insight into the following questions:

1. Does gender presence impact a STEM YouTube channel's popularity?
2. Does a STEM video's gender presence influence YouTube viewer responses and sentiments?
3. Is YouTube a hostile environment for female science communicators to effectively engage audiences?

In order to understand disparities between the gender presences of popular YouTube STEM-themed channels, YouTube's inbuilt popularity indicators (channel subscribers, channel views, video likes, video dislikes and video views) were analysed for variance in audience responses. A sentiment analysis of video comments was conducted to further investigate YouTube audience reactions between different gender presences.

This investigation represents a step in a wider investigation of diversity in the world of STEM communication online. In future work, we hope to explore the ways others – based on ethnicity, class, sexual orientation, non-binary gender identification or physical ability – may be marginalised in online STEM forums, and the ways those marginalisations may intersect. Here it should be acknowledged that the largely binary gender categorisation underpinning this current investigation may provide only partial insight into the matter, and should be built on and further theorised in future work (see Francis and Paechter, 2015).

Women in STEM and science communication

Women account for 30% of scientific researchers worldwide, with just one in five countries showing male to female parity. In Australia, male and female students enter tertiary science at equal rates, yet women hold less than 10% of senior academic positions and fellowships (Luntz, 2011). Both anecdotal and survey reports state that women in STEM face greater hurdles to success than their male counterparts (Baker, 2011).

There has been an academic shift away from theories attributing gender gaps to inborn differences in abilities and instead towards wider societal influencers of gender norms, perpetually reinforcing and shaping respective interests (Valian, 2014). According to role congruity theory, implicit

biases against women in STEM emerge due to society's expectations of scientists as agentic, objective, organised, and assertive; qualities more readily associated with notions of masculinity (Huge et al., 2013). The theory hypothesises that incongruence between these and traditional female characteristics results in biased perceptions of women's possession of such traits, or against women's possessing them over and above men (Koenig et al., 2011). Gender incongruity has been found to predict researchers' topic choices according to gender role expectations as well as characterisations of scientific fields, for example, the communal qualities of social sciences as female in comparison to physics and maths which are more readily perceived as male (Huge et al., 2013; Knobloch-Westerwick and Glynn, 2013). It has been hypothesised that traditional portrayals of science as cerebral contradict the gendered desires of adolescent girls, who are reportedly more engaged by ideas of glamorous, interactive, hands on and 'practical' pursuits (Archer et al., 2013).

Gender schema theory describes how children learn appropriate gendered roles according to socialising agents such as parents, peers, teachers and the media (Long et al., 2010). Surveys of adolescent occupational interests have demonstrated that perceptions of gender appropriateness are often shaped by an individual's socialisation experiences (Turner and Lapan, 2005). Social research suggests that media representations of women in science are highly influential at many levels, while the significance of female STEM role models in motivating young women's aspirations has been much speculated upon, exposure to female scientists has been found to affect both boys and girls positively (Evans et al., 1995; Steinke et al., 2012). Studies have also shown deficient portrayals of female scientists by mass media results in a masculinised perception of STEM among girls and a disbelief in their own ability to pursue science (Long et al., 2010; Steinke, 1999).

While multiple factors are thought to contribute, researchers argue that mass media marginalises female scientists through tokenistic and distorted depictions, reinforcing gender stereotypes and segregations (Chimba and Kitzinger, 2010). Referencing the 'Matthew effect' – in which the most prominent scientists are often over recognised and rewarded – researchers have pointed to a 'Matilda effect', in which women scientists suffer a systematic underestimation and under-recognition of their work (Huge et al., 2013; Rossiter, 1993). Gender has been shown to affect how scientists are represented and used as sources by the media, with women cited far less and frequently as secondary sources, also eliciting more comments regarding their appearance (Kitzinger et al., 2008; Niemi and Pitkänen, 2017).

Although it is beyond the scope of this article, it should also be acknowledged that while women face structural marginalisation in scientific careers, marginalisation also occurs along lines of ethnicity, class, sexual orientation and physical ability. Moreover, such forms of discrimination and marginalisation compound and intersect, meaning the barriers faced by middle class abled bodied heterosexual White women are not the same as those faced by all women.

Given the persistent discrimination against women in STEM sectors – despite regulations and active campaigning – it is unfortunate that corresponding trends of gender imbalances have continued within online communities (Guadagno et al., 2011).

YouTube and gender

Since its inception in February 2005, YouTube.com – the primary social media platform for uploading, viewing, commenting and promoting online videos that 'connect, inform and inspire' (YouTube, 2015) – is one of the most visited websites in the world. However, despite optimism of a democratic Web 2.0 in which users are able to bypass traditional media barriers to share, discuss, modify and co-create material themselves, YouTube has been found to represent far less multicultural and gender diversity in its highly popular videos and channels than traditional television

networks (Kietzmann et al., 2011; McMillan and Wotanis, 2014). Szostak (2013), for example, has reported that only 6 of the 100 most subscribed YouTube channels in 2013 featured women.

It has been suggested that minority and gender disparities observed on YouTube are a reflection of real-world social imbalances in the workforce and professional leadership roles (McMillan and Wotanis, 2014). However, anecdotal and qualitative accounts suggest that a major factor in YouTube's gender imbalance is a hostile environment – perhaps made possible by online anonymity (Thelwall et al., 2012) – that discourages women from participation (McMillan and Wotanis, 2014). Here a comparison of the highly popular YouTube channel JennaMarbles against a similar male counterpart found that although both received positive feedback, JennaMarbles was four times more likely to receive criticism (18% vs 4%) discussing her personality, gender or video content (McMillan and Wotanis, 2014).

Science communication and YouTube

Research indicates that consuming scientific knowledge from diverse content mediums and a range of sources facilitates greater scientific knowledge acquisition (Brossard, 2013). However, mere availability of information is insufficient, as audiences must be motivated to pay attention (Meyer and Schroeder, 2009). It is therefore necessary for science communicators to engage the interest of an intended audience, requiring an understanding of how different publics engage with various media and how they respond and interact with messaging factors.

Many scientists have been active in taking their communication efforts directly to the public via the Internet and social media (Brossard, 2013). A constantly growing repository of formal and non-standard scientific content is now available online, much of it open access, with YouTube becoming a popular medium for promoting research and education to global audiences. YouTube has developed beyond an entertainment platform, providing ready access to a wide variety of science content. A 2012 study by Kousha et al. observed scientists tweeting video links and found six broad categories: scientific demonstration, public dissemination, education, talks by academics, information about scientists and science comedy, with the most popularly viewed category found to be research communications targeted at public audiences.

Online STEM-related videos have been observed to attract significant interest, as demonstrated by the success of TED.com (Technology, Entertainment and Design), one of the world's most popular online video producers (Sugimoto et al., 2013). Therefore, by increasing the reach and diversity of science communication, social media platforms such as YouTube offer a genuine opportunity to enhance the public awareness of science (Kousha et al., 2012). It is also vital for science communicators to maximise the visibility of their presences in order to successfully impact potential audiences online (Meyer and Schroeder, 2009).

Sugimoto et al. (2013) analysed the popularity of TED talk videos against their presenter's credentials and characteristics, assessing if relative popularity had any consequential impacts on academic citations. The study found that although 79% of the talks were by non-academics, online audiences preferred the presentations by academics, which also inspired more comments. While academics who did present tended to have senior credentials and were cited more than average, these videos were found to have had no significant impact on their prospective likelihood of citations. Another study by Tsou et al. (2014) analysed TED talk video comments via both YouTube and TED.com, finding that talks presented by women elicited more personally directed, emotional and polarised responses from audiences and that this effect was increased on YouTube.

With media progressively uploaded and pushing older resources further back in search lists over time, there is increasing competition to dominate the limited attention space (Meyer and Schroeder, 2009). YouTube allows users to easily search and access relevant videos using keywords when and

where they desire, rather than as designed by a broadcaster or publisher, also providing recommendations according to patterns of behaviour and interest. Researchers are yet to fully understand how searching and viewing behaviour in turn shape the visibility and impact of Internet information as there are over 5 billion Google web searches a day, dictating the visibility of material and access to media and knowledge (Brossard and Scheufele, 2013; Meyer and Schroeder, 2009). However, a 'winner takes all effect' or 'Matthew effect' is applicable to the visibility and consumption of online content, meaning that efforts by the most prominent scholars and popular science communicators are more accessible and likely to be noticed by audiences (Meyer and Schroeder, 2009).

The self-selecting nature of YouTube search algorithms are thought to have a hand in the hostile environment for female and minority participation (McMillan and Wotanis, 2014). It's been found that 97% of YouTube's audience predominantly view the site's most popular 20% of video uploaders (Ding et al., 2011). An investigation of YouTube STEM video and channel popularity by Welbourne and Grant (2015) found that the most popular channels were user generated rather than professional and also featured continuous hosts instead of discontinuous presenters. Although the study identified that women were underrepresented, very little effect between gender and popularity was detected (Welbourne and Grant, 2015). Interestingly, given criticisms of traditional media's lack of female representation within scientific programming, more women were found to appear in professionally generated channels than user generated (Shaha, 2010; Welbourne and Grant, 2015).

Through analysing the numbers of subscribers, video views, likes, dislikes and comments, in combination with sentiments expressed by viewers within video discussions of popular STEM-themed YouTube channels according to their gender presence, we hope to gain insight into the following questions:

1. Does gender presence impact a STEM YouTube channel's popularity?
2. Does a STEM video's gender presence influence YouTube viewer responses and sentiments?
3. Is YouTube a hostile environment for female science communicators to effectively engage audiences?

2. Method

STEM-themed channels according to the Web of Science citation categories with at least five videos were identified from among the 'Education' and 'Science & Technology' 'Top 500' Socialblade and 'Top 200' Vidstatsx YouTube Channel charts (Science Citation Index, 2012; Socialblade, 2014a, 2014b; VidStatsX, 2014a, 2014b, 2014c, 2014d). Channels were then further investigated to identify and categorise their gender presences and, as only 32 female hosted and narrated channels were identified, 21 channels from BrainScoop's recommended list of female STEM channels 'Where My Ladies At?' were also included in the sample ($N=391$) (thebrainscoop, 2013). Gender categorisation here drew on self-identification of presenters (such as pronoun use), information from BrainScoop's Where My Ladies At? Video, and the linguistic and semiotic performances of the presenters, discussed by both authors. At this point, it should be recognised this simplistic gender categorisation may not reflect the truth of the matter, and ignores – and may indeed contribute to – the difficulties faced by those who may not present according to cisgender norms (see Francis and Paechter, 2015). In future work in this space, we plan to explore responses to other forms – and intersecting forms – of marginalisation, and non-binary gender identification of YouTube presenters.

There was a great deal of variation in video presentation styles and male to female presences, therefore channels were classified according to six broad categories, Continuous Male Host ($n=106$), Continuous Female Host ($n=29$), Male Voice-over ($n=86$), Female Voice-over ($n=21$), Neutral/

Table 1. Coding categories used for the sentiment analysis with short description of the corresponding comments.

Sentiment categorisation	Comment description
Appearance	Comments either slighting or favourably discussing the appearance of video creator(s), video host/guests, video content or channel
Sexual and sexist	Sexualised and sexist comments either slighting or favourably directed towards video creator(s), video host/guests, video content or channel
Hostile	Hostile and abusive comments directed towards video creator(s), video host/guests, video content or channel
Positive	Positive and complimentary comments directly regarding video creator(s), video host/guests, video content or channel (excepting Appearance/Sexual)
Critiques and negative	Critiquing or negative comments directly regarding video creator(s), video host/guests, video content or channel
General discussion and neutral (and also other)	Comments that were not clearly positively or negatively directed towards video creator(s), video host/guests, video content or channel. General topic discussions, self-promotions, non-specific comments and interactions between commenters were included in this category

Discontinuous Hosts ($n=125$) and Teams of Hosts ($n=24$). Non-English language channels and those with disabled comments section were excluded from Stages 2 and 3 of the analysis.

For the purposes of exploring gender effects on YouTube STEM communication by examining differences in audience reception or sentiment to the gendered presences of channels and videos, a simple random sample of 15 channels from each category were selected using Microsoft Excel's random number generation. From these, the total channel subscribers and channel views, and video likes, video dislikes, video views and video comments of five randomly sampled videos from each channel were collected and compared. A sentiment analysis was conducted for up to 100 comments from each of the videos, with a total of 23,005 comments examined. There was a great deal of variation in the number of comments received between channels; therefore, if the video had fewer than 100 comments, all were scrutinised and if greater, as some videos had thousands, a random sample was taken from the entire discussion.

Each comment was single-coded for sentiment according to a rubric developed (see below) to reflect the research questions and the data; however, comments by the video creators themselves and in non-English languages were excluded from the analysis. It should also be noted that where the number of video comments exceeded 100, the random sampling method will have led to their loss of context within the discussion; however, the sentiment categories were designed to detect overall intent towards the content creators, accommodating this shortfall to an extent (Table 1).

IBM SPSS Statistics 20 for Windows was used for analysis of the results. The impact of gender presence on audience responses was assessed using a Univariate Analysis of Variance (ANOVA) and also, as Levene's tests indicated unequal variances, post hoc Games–Howell analyses for further examination of interactions.

3. Results

Stage 1: Popularity of YouTube STEM channels in this sample categorised by gender presence

Very few female presences were collected from the Socialblade and Vidstatsx top YouTube Education or Science & Technology Channel Lists; therefore, 21 additional channels were sourced

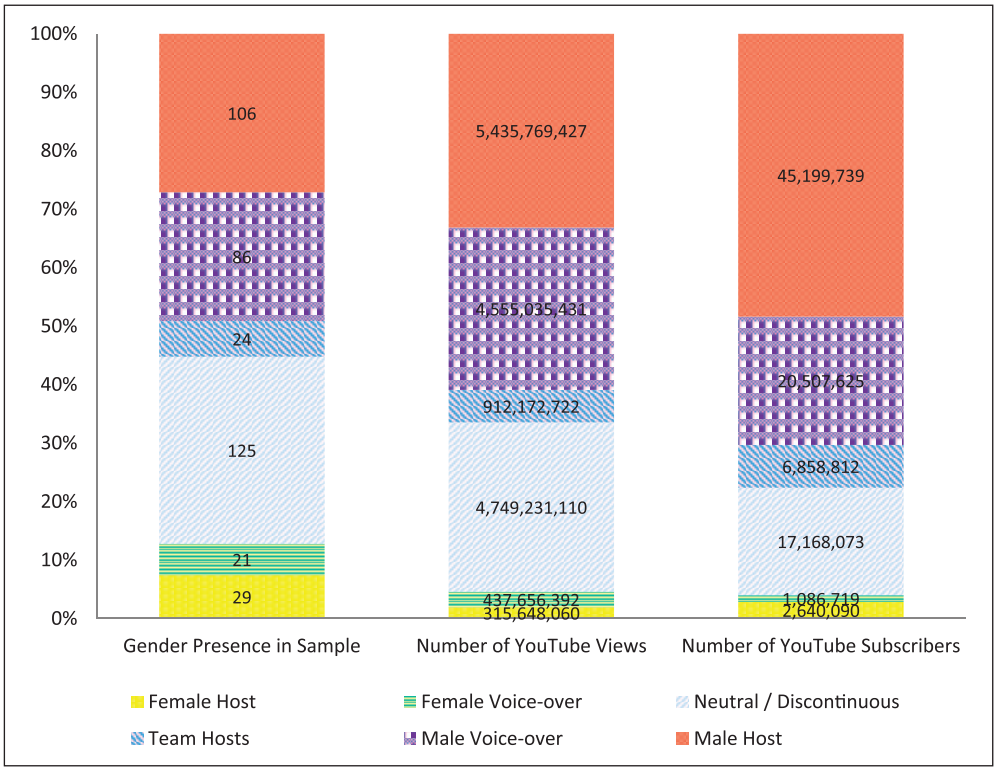

Figure 1. Relative proportions of YouTube channel sample ($N = 391$), channel subscriptions and channel video views by female host, female voice-over, gender neutral/discontinuous, team host, male voice-over and male host gender categories from top 'Education' and 'Science and Technology' and BrainScoop's 'Where My Ladies At?' list of channels.

from the specialised female STEM YouTube channel list 'Where My Ladies At?', accounting for 13/29 female host, 5/21 female voice-over, 1/24 teams and 1/25 neutral/discontinuous channels out of the channels sampled (thebrainscoop, 2013). Of the top 50 most subscribed channels in the sample, only 2 had female presences, 1 hosted and the other voiced. Of the top 50 highest viewed channels, 4 were female voiced-over and 2 were female hosted. The inclusion of BrainScoop's recommended female YouTube creators in the female, neutral and team gender presence samples should be noted when considering to what extent the sample can be considered representative by gender presence. These choices were made with the goal of detecting any effects of gender on sentiments and responses of YouTube STEM audiences with the scope of this study in mind. The results can be considered a demonstration of audience sentiments and responses within the gender categories rather than the population overall.

The stacked column chart in Figure 1 along with the box plots in Figure 2 depict total channel subscriptions and total channel views relative to gender presence and style of video in this sample. Although male hosted and voiced-over channels were the second and third most prevalent gender categories within the sample of STEM videos, respectively, they accumulated the highest share of channel views with the highest means, $M = 51{,}280{,}844$ (164,229,043), $M = 52{,}965{,}528$ (164,229,043) and subscriptions $M = 426{,}413$ (991,539), $M = 238{,}461$ (486,494). Relatively few team hosted channels were found within the sample, yet they accumulated proportionally greater

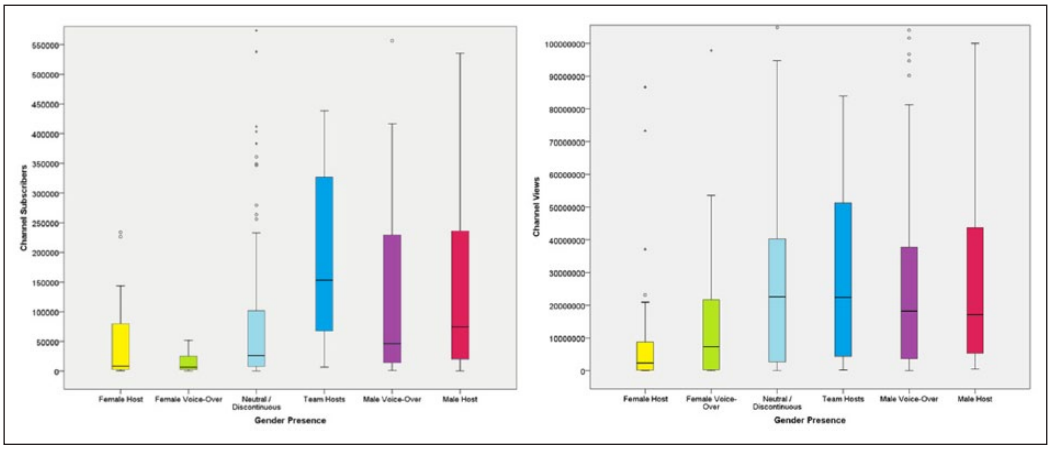

Figure 2. Mean subscribers and views of total YouTube channel sample ($N = 391$), female host ($n = 29$), female voice-over ($n = 21$), neutral/discontinuous ($n = 125$), team hosts ($n = 24$), male voice-over ($n = 86$) and male host ($n = 106$) gender categories.

views, $M = 38{,}007{,}197$ (46,027,907), than neutral/discontinuous, $M = 37{,}993{,}849$ (73,508,861); female hosted, $M = 10{,}884{,}416$ (21,027,563); and female voiced-over channels, $M = 20{,}840{,}781$ (31,485,554). Team hosted channels, $M = 285{,}784$ (407,660), were also subscribed more, with less variability and higher values than neutral/discontinuous, $M = 137{,}345$ (368,907); female hosted, $M = 91{,}038$ (199,229); and female voiced-over, $M = 51{,}749$ (168,486), channels.

Stage 2: Further analysis of YouTube STEM channels categorised by gender presence

This section now turns to an analysis of the impact of gender presence on YouTube's inbuilt quantitative popularity indicators (channel subscribers, video likes, dislikes and number of comments) normalised by video views (Figure 3).

Channel subscribers to channel views. The ANOVA revealed that gender presence did have a large effect on the rate at which viewers subscribed to a channel following a video viewing, $F(5, 84) = 4.24$, $p = .0017$, $\eta^2 = 0.20$. This ratio was highest for female hosted channels, $M = 3.76$ (3.82), and had comparatively larger variance skewed to the right than other gender presence samples. Games–Howell post hoc analysis found that female hosted channels had a significantly higher proportion of subscriptions to views than all the other gender categories; female voiced-over, $M = 1.27$ (1.73); neutral/discontinuous, $M = 1.15$ (2.58); team hosts, $M = 0.81$ (0.61); male voice-over, $M = 0.75$ (0.82); and male hosted, $M = 1.43$ (1.18). Male hosted channels were subscribed significantly more often upon view than male voiced-over and team hosted.

Video likes. The ANOVA found that gender presence had a medium effect on the proportion of video likes to video views $F(5, 444) = 15.14$, $p < .001$, $\eta^2 = 0.15$. Games–Howell post hoc analysis showed that female hosted channels gained significantly more video likes per view, $M = 3.42$ (2.52), than female voiced-over, $M = 1.25$ (1.89); neutral/discontinuous, $M = 1.53$ (1.19); team hosted, $M = 2.28$ (1.1); and male voiced-over, $M = 2.06$ (1.86). Other significant differences also revealed by the Games–Howell analysis were that both male hosted, $M = 2.71$ (1.61), and team

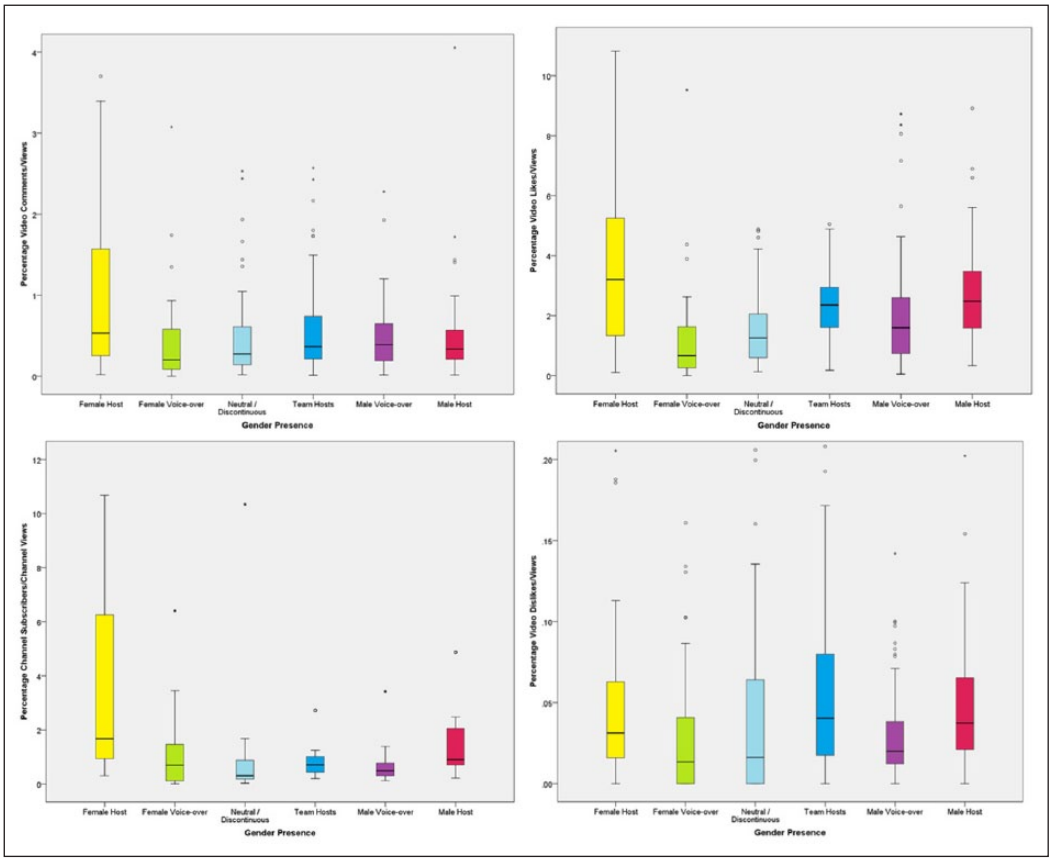

Figure 3. Box-plots depicting channel subscribers to channel views, and video likes, dislikes and comments to video views for gender categories.

hosted channels were also liked significantly more often in ratio to views than female voiced-over and neutral/discontinuous channels.

Video dislikes. The ANOVA found that gender presence had a small effect on the proportion of dislikes to views, $F(5, 444) = 2.38$, $p = .038$, $\eta^2 = 0.026$, between channel categories, with female hosted, $M = 0.13$ (0.39), videos the most disliked upon view in comparison to male hosted, $M = 0.06$ (0.09); team hosted, $M = 0.07$ (0.09); neutral/discontinuous, $M = 0.06$ (0.14); male voiced-over, $M = 0.04$ (0.07); and female voiced-over, $M = 0.03$ (0.07). However, the Games–Howell post hoc analysis for the proportion of video dislikes to video views showed no significant differences between the gender presences.

Video comments. The ANOVA revealed that gender presence did have a small effect on the proportion of comments received in relation to video views, $F(5, 444) = 3.14$, $p = .0084$, $\eta^2 = 0.034$. Games–Howell post hoc analysis for the ratio of video comments to views found that female hosted channels, $M = 1.04$ (1.11), were commented on significantly more than neutral/discontinuous, $M = 0.45$ (0.51); male voiced-over, $M = 0.48$ (0.4); male hosted, $M = 0.54$ (0.82); and team hosted, $M = 0.57$ (0.56), though female voiced-over channels, $M = 1.26$ (3.74), had the most comments in relation to views they were not found to be significantly different to other presences.

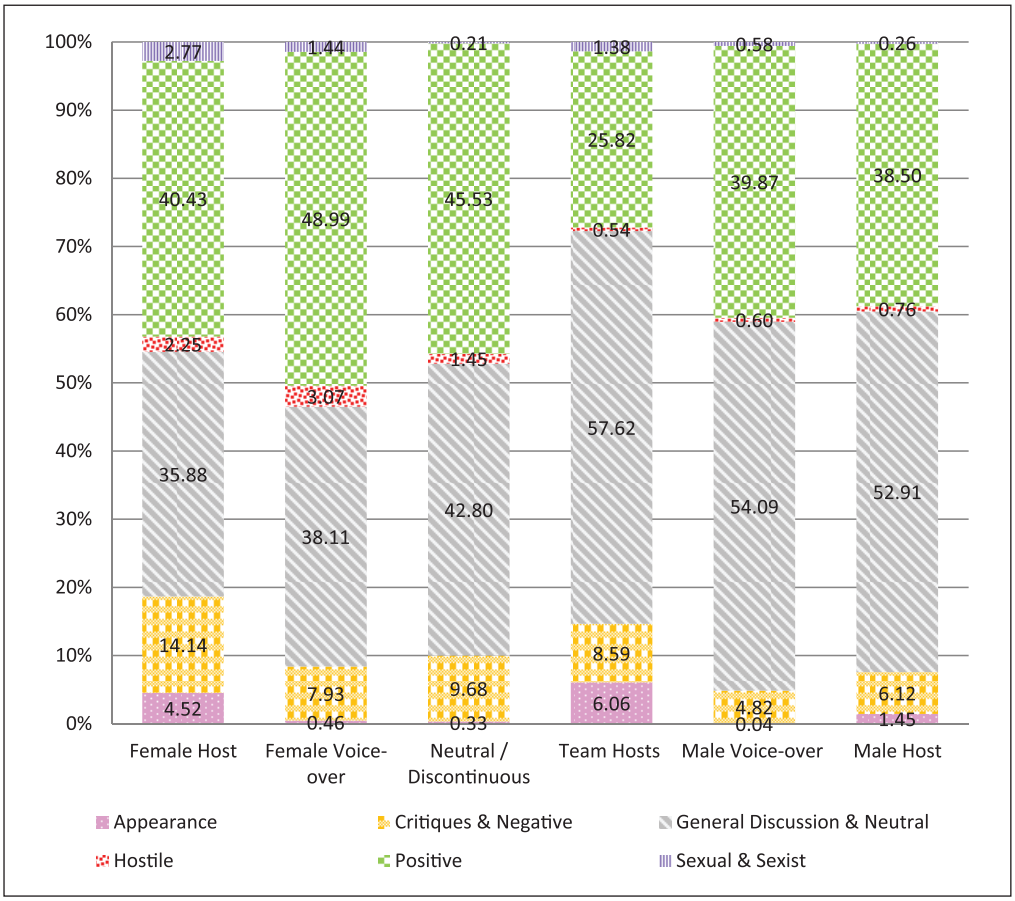

Figure 4. Column graph depicting overall mean proportion of comment sentiments from video discussions by gender presence category.

Stage 3: Sentiment analysis of video comment threads from sampled YouTube STEM channels by gender presence

This section now turns to sentiment analysis of video comment threads categorised by gender presence (Figure 4).

Appearance comments. The ANOVA revealed that gender presence had a medium effect on the proportion of appearance-related discussion within the video comments between categories, $F(5, 444) = 9.41$, $p < .001$, $\eta^2 = 0.096$. Games–Howell post hoc analysis found that appearance remarks about guests or hosts made up a significantly larger proportion of video discussion for the female hosted channels, $M = 2.01$ (2.81), and team hosted channels, $M = 1.99$ (3.15), than, somewhat unsurprisingly, female voiced-over, $M = 0.13$ (0.60); neutral/discontinuous, $M = 0.15$ (0.63); and male voiced-over, $M = 0.04$ (0.26), channels. Male hosted channels, $M = 1.40$ (7.73), were not found to have any statistically significant difference with any of the other gender presences.

Critiques and negative comments. The ANOVA found that gender presence did have a small effect on the proportion of negative and critical discussion within the video comments, $F(5, 444) = 3.19$, $p = .008$, $\eta^2 = 0.035$. While videos from male hosted, $M = 6.12$ (7.49), and voiced-over, $M = 4.82$ (6.48), channels had the lowest mean proportions, Games–Howell post hoc analysis found the only significant differences were that team hosted, $M = 8.59$ (8.67), and female hosted, $M = 14.14$ (24.35), channels had significantly higher proportions of critiques and negative comments than male voiced-over channels. Male hosted, female voiced-over, $M = 7.93$ (20.19), and neutral/discontinuous, $M = 9.68$ (17.8), presences were not found to have any significant differences to the other gender presences.

General and discussion comments. The ANOVA revealed that gender presence did have a medium effect on the proportion of neutral and general discussion in video comment threads, $F(5, 444) = 8.88$, $p < .001$, $\eta^2 = 0.091$. Games–Howell post hoc analysis found that both female hosted, $M = 35.88$ (25.20), and voiced-over, $M = 38.11$(31.68), channels had significantly less neutral and general discussion than male hosted, $M = 52.91$ (23.52); male voiced-over, $M = 54.09$ (20.02); and team hosted, $M = 57.62$ (25.06) channels. Neutral/discontinuous channel presences, $M = 42.8$ (31.95), were also found to have a significantly smaller proportion of neutral and general comments than team hosts.

Hostile comments. The ANOVA revealed that gender presence did have a small effect on the proportion of hostile comments directed towards the video, video-host or channel, $F(5, 444) = 3.38$, $p = .005$, $\eta^2 = 0.037$. Games–Howell post hoc analysis found that female hosted, $M = 2.25$ (4.29), channels had significantly higher proportions of hostile comments than male voiced-over, $M = 0.60$ (3.88), and team hosted, $M = 0.54$ (1.38), channels. Male hosted, $M = 0.76$ (3.88); female voiced-over, $M = 3.07$ (9.00); and neutral/discontinuous, $M = 1.45$ (4.81), presences were not found to have any statistically significant differences to the other gender presences.

Positive comments. The ANOVA indicated that gender presence did have a medium effect on the proportions of positive comments received within the overall discussion of videos, $F(5, 444) = 5.95$, $p < .001$, $\eta^2 = 0.063$. Games–Howell post hoc analysis found that team hosted channels, $M = 25.82$ (21.33), had a significantly lower proportion of positive comments among their video discussion than all other gender presences; female voiced-over, $M = 48.99$ (37.29); neutral/discontinuous, $M = 45.53$ (32.29); female hosted, $M = 40.43$ (29.66); male voiced-over, $M = 39.87$ (22.27); and male hosted, $M = 38.50$ (22.24).

Sexual comments. The ANOVA revealed that gender presence did have a small effect on the proportion of sexual video comments, $F(5, 444) = 5.03$, $p < .001$, $\eta^2 = 0.054$. Games–Howell post hoc analysis found that female hosted, $M = 2.77$ (4.82), channels had significantly more sexual comments within their discussions of videos than neutral/discontinuous, $M = 0.21$ (1.66); male hosted, $M = 0.26$ (0.63); and male voiced-over, $M = 0.58$ (2.06). Team hosted, $M = 1.38$ (4.11), and female voiced-over, $M = 1.44$ (6.11), channels were not found to be significantly different to the other gender presences.

4. Discussion

The significant differences between the gender presences in the sample revealed by Stage 1 analysis of channel subscriptions and channel views were not unexpected given the relative few female presences as either hosts or narrators within the top ranking YouTube ‘Science and Technology’

and 'Education' channel lists. The results showed that female hosted channels in the sample had significantly fewer subscribers than male hosted and female voiced-over channels.

Stage 2 ANOVA results found that gender presence had a small effect on the differences in the number of video dislikes and video comments per video view, a medium effect on likes per view, and a large effect on the proportions of subscribers to views.

Interestingly, female hosted channels, despite inspiring more engagement from viewers (with significantly higher proportions of subscriptions, likes and comments per view), suffered greatly in terms of popularity. While the results indicate that hosted channels did inspire higher engagement than narrated or neutral/discontinuous channels, female voiced-over channels had relatively high means in terms of proportions of subscription, likes, dislikes and comments per view, also conforming with findings that less popular videos appear to receive more acute audience responses than those with large audiences (Chatzopoulou et al., 2010).

Stage 3 sentiment analysis ANOVA results were sought to further investigate the effect of gender presence on YouTube STEM audiences. We found that gender presence appears to have a small effect on the differences between the proportions of negative/critical, hostile and sexist/sexual comments received and a medium effect on the proportions of appearance, neutral/general and positive comments received. Female hosted and team hosted channels appear to be the most significantly different categories, with less positive and neutral/general discussion and more appearance, critical/negative, sexual and hostile commenting by viewers.

The sentiment analysis results align with findings by Tsou et al. (2014), that TED Talks by women received more personally and emotionally polarising comments from YouTube audiences. Videos discussions from female hosted and neutral/discontinuous channels contained significantly less general/neutral discussion. It has been argued that highly visible comment sections of online science communication media facilitate a kind of 'post-peer review' allowing expert discussion of content (Rice, 2013). However, the nature and tone of online comments have been shown in turn to influence audience perceptions of the science content, with implications that could be problematic for women's science communication practice; that more intensely debated discussion correspondingly enhances polarising views (Brossard, 2013; Brossard and Scheufele, 2013).

Common themes within the appearance- and sex-related comments received by team hosted videos were sexualising relationships between video hosts or guests and comparing or critiquing their appearances against each other. Female hosts received significantly more hostile and sexist/sexual remarks than any other presence along with significantly higher proportions of appearance comments. Although male hosts also received relatively more than voiced-over or neutral/discontinuous presences, the results were far more vivid for female hosted channels. This commenting behaviour was reported by BrainScoop's host Emilie Grasilie in the 'Where My Ladies At?' video discussed above, along with her subsequent discomfort interacting with guests due to the sexual innuendo and commentary in her video comment threads (BeMiller, 2013; thebrainscoop, 2013). Grasilie sparked a great deal of discussion after posting the video in response to abusive YouTube comments, inspiring further discussion about the difficulties for women communicating science on YouTube and the detrimental impact of gender bias on women's participation, acknowledgement and success in STEM (BeMiller, 2013; Fenner, 2013; Lovell, 2014; thebrainscoop, 2013).

It has been suggested that as YouTube is a participatory culture, the marginalisation of women communicating STEM on YouTube can be viewed as both an indication of how society perceives and interacts with women doing and discussing science, as well as a reflection of the issues women face in the STEM industries (Chau, 2010). However, Vanessa Hill, creator of YouTube channel BrainCraft, has commented on the difficulties of entering YouTube's tight-knit STEM community: that social networking aspects of YouTube participation are another hurdle for many newcomers, 'There are a

lot of other educational channels … they've all been around for a couple years, and they have this whole in-group that you're not a part of because you're a new creator' (Lanning, 2014, para. 9).

Definitive findings regarding the third research question about the relative ability of female science communicators to engage YouTube's audiences successfully cannot be fully answered by this study, yet the sentiment analysis results indicate that videos with female presences are received differently by YouTube viewers to those with male hosts, that female creators receive greater hostility, appearance and sexual commentary along with negative criticisms within their discussion threads.

Female science communicators have made a variety of choices in response to YouTube's notorious environment: choosing to narrate videos rather than present or host in person, disabling comment threads, ignoring or not engaging with comment threads or choosing other platforms. Cara Santa Maria, a science communicator successful on many online platforms and also featured on popular YouTube science channels, acknowledged her preference to engage with her audience through Facebook or Twitter rather than YouTube, stating that the 'troll: healthy engagement ratio is too high. There is a lot of vitriol on YouTube, including threatening language, violence, and cruelty. I'm simply not interested in making that a part of my career' (Maria, 2014, para. 3). While ViHart chooses not to engage within YouTube threads, BrainCraft's Hill stated her strategy in combating abuse from YouTube 'trolls' was direct confrontation, along with supportive commenting from her viewers (Lanning, 2014; Popova, 2013), which, as audience engagement has been found to be relatively high for female presences, could be an effective strategy towards harnessing YouTube's participatory culture.

It has been hypothesised that a deficiency in female role models and mentoring contributes to a lack of confidence and sense of belonging for women pursuing STEM (Shen, 2013). While this aligns with much of the literature discussed above, a 2012 study conversely found that adolescent girls exposed to counter-stereotypical female STEM role models were more likely to be de-motivated, perceiving these successes as unattainable, highlighting the complexities of social influences and the need for multiple voices in the public sphere (Betz and Sekaquaptewa, 2012).

The highly popular and influential host of YouTube channels SciShow and CrashCourse, Hank Green, gave his view on the disparity:

> It's not like there are people saying 'Woah now! I'm not sure if we can have a lady talking about science'. It's open to everyone … YouTube is largely male in general, I think, for a few reasons. One, it can be pretty abusive, which I'm sure you've seen. Two, the first round, at least, are the attention-seekers who don't care what they're doing as long as people watch, and that seems to be a more male trait (we're scientists, we can agree that there are psychological trends in the sexes.). (Manaster, 2013, para. 5)

The main limitation, or filter, to be noted when interpreting both Stage 2 and Stage 3's sentiment analysis results are that the popularity indicators and comments included were from randomly sampled channels within specific gender categories, rather than a purely random selection of comments and videos. Consequently, the results are more an average reflection of channels within the gender categories rather than the gender presence overall.

A second limitation of Stage 3 sentiment analysis was in the method of sampling, as more comments from male hosted and male voiced-over channels were analysed than the other gender presences as many of them had videos with fewer than 100 comments. YouTube STEM channels have significant variety and quality in their production values, presentation styles, subjects and content; however, other than whether hosted or narrated, these differences were not taken into account by the analysis. Another factor that was not taken into account was the YouTube channel's country of origin. However, these choices were made in line with the scope of this study, to detect the effect of gender on sentiment responses of YouTube STEM audiences. It should also be noted at this point

that the somewhat active video engagement of liking, disliking or commenting may not accurately reflect the wider sentiments of all viewers.

5. Conclusion

The results of this study reveal that gender does affect the reception of and interaction with STEM videos and channels on YouTube. Despite progress towards greater equality in STEM, female science communicators on YouTube continue to face bias and social discrimination, impacting their popularity and reception among viewers. The average female communicator received more comments per view, with larger proportions of hostile, sexual, appearance and negative/critical commenting.

As YouTube presents unprecedented and growing audiences with whom to communicate STEM content with, it is important not only to maximise visibility and engagement with potential audiences but also to provide them with a diversity of voices and presenters. It is therefore vital for more women to participate fully and successfully within the YouTube STEM community. Although there's been previous research into uncovering and revealing barriers affecting women in the STEM industries and also in various science communication media, real strategies towards overcoming discrimination for full female participation and equality are yet to be established. That female hosted presences suffered in popularity despite having higher engagement upon view could be a promising avenue of further investigation.

This study presents a range of useful directions for future investigation. In particular, it is important to extend on this work to explore the ways that intersecting forms of discrimination and marginalisation – such as those based on ethnicity, class, sexual orientation, physical ability and non-cisgender presentation – may compound in the STEM YouTube space. Other avenues for future work – particularly given the imperfect nature of using text analysis to proxy wider audience sentiment – include exploring ways those who don't explicitly interact with a video (by commenting, liking or disliking, for example) are – or are not – represented by those who do, and their reaction to gender presence among YouTube's STEM communicators. In all this, it is hoped that research can uncover factors that those traditionally marginalised from STEM careers can use to assist in bringing new and diverse STEM communicators to YouTube and other online and popular media, and in turn to the wider STEM community.

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