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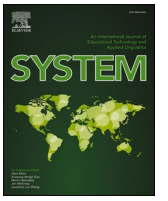

Talking science: Women scientists' engagement in spoken public science communication online

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ABSTRACT

We use survey data from women scientists in biology and health sciences to explore digital spoken genres of public science communication and the use of digital tools and resources to produce them. Our results show that more than half of the respondents engage in digital spoken practices that promote scientific culture on digital media. Notably, the type of research methodology used by the respondents influences their level of engagement in these practices, with those using quantitative methodologies showing the lowest level of engagement. Both traditional digital tools (content, audio, and video editing tools) and new generation digital tools (open multimedia resources, AI) are not yet widely used, despite their potential for crafting persuasive texts for science outreach. We found significant statistical associations between the use of digital tools and the importance that the respondents and their professional contexts attribute to specific digital spoken genres. In light of these findings, we argue for greater recognition of digital public science communication practices at the policy level. We also recommend implementing collaborative, multimodal composition tasks as a pedagogical approach to help scientists develop oral and digital communication skills for effective online science communication.

1. Introduction

1.1. Science communication online

Digital transformation has been a major driving force for the widespread adoption of the Open Science (OS) culture. Scientists today are required to communicate their scientific results to society, moving beyond the scientific community (Fecher & Friesike, 2014). In the EU context, the imperative to engage in public science communication cuts across researchers' levels of expertise, from first-stage researchers to leading researchers. EURAXESS research profile descriptors[1] explicitly emphasize the importance of knowing how to communicate with society in general, explaining the outcome of research both within and beyond the scientific community.

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[1] https://euraxess.ec.europa.eu/career-development/researchers#research-profiles-descriptors.

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However, while digital transformation offers digital affordances to support OS science communication practices, it might make it more evident the significant gender disparity of the EU researchers' workforce, 2.15 million researchers, with men accounting for circa 65% in 2021 according to the European Commission EU stats.[2] This gender gap, which has shown a marginal decrease in the past years, points to an essential but often under-researched population in the context of digitally mediated public science communication, women researchers. Survey-based studies of women researchers report that they demand focused training in digital science communication and the use of digital tools to support digital communication practices (Birch-Beecas et al., 2023; Pérez-Llantada et al., 2022). Recent research also shows that low engagement in these practices is attributed to lack of time to familiarize oneself with new digital genres, lack of incentives, recognition and training, or institutional policy constraints that impose pressure to publish in high-impact factor journals (Birch-Becaas & Reynolds, 2024; Pérez-Llantada et al., 2025). These contextual impacts echo Tusting's assertion regarding the influence of 'genre regimes'. Using the example of the UK's REF framework, Tusting (2018) criticizes the high value placed on journal article metrics by some academic and research promotion systems. Others have argued that the societal impact of scientific outreach activities is not recognized beyond journal article publications (Sugimoto et al., 2013; Thelwall et al., 2012).

When setting up this study we were also aware of other gender disparities. For example, findings from the scientometrics literature show that women researchers on YouTube are underrepresented, accounting for only 27% of all presenters and that their level of popularity is lower compared to male researchers (Sugimoto et al., 2013). Their research productivity is also lower compared to their male counterparts (see, e.g., Aksnes et al., 2019, for the case of Norwegian women scientists). Targeted training to help researchers, particularly women, become digitally ready and resilient, and capable of 'talking science online' is crucial. This would empower them to participate fully in the rapidly changing landscape of science communication, ultimately fostering a more inclusive and better equipped workforce in the EU and beyond.

1.2. *Context of the study*

Open Science has promoted new forms of communicating science on the Internet and triggered inclusive collaborative practices that have the potential to engage society in scientific research (Dai et al., 2018; Puschmann, 2014). Today, e-platforms with integrated interactivity tools and multimedia applications allow scientists to share their research with a wide range of audiences by presenting it in different formats. JoVE, the *Journal of Visualized Experiments*, publishes visually engaging and easy-to-understand video methods articles demonstrating scientific research step-by-step (Hafner, 2018). Original research articles are accompanied by an associated video abstract, which summarizes the content of the article in audiovisual format (Spicer, 2014). Science popularization formats include explainer videos, vlogs, and science podcasts (Riboni, 2020; Zou & Hyland, 2024), and in participatory science, video pitches with audiovisual and oral texts are employed in crowdfunding projects online (Reid & Anson, 2019; Vivas-Peraza, 2022). These examples demonstrate how digital science communication enables researchers to engage with diverse audiences, regardless of their background and levels of expertise in scientific matters.

Digital genres of public science communication have been conceptualized by rhetorical genre studies as 'rhetorical hybrids'. Miller (2016, p. 6) explains that rhetorical hybrids involve genre "continuity through some form of 'inheritance'" (i.e., an existing genre). Miller uses blogs as an example, noting that they incorporate features of the traditional lecture genre alongside with the multimodal features typical of digital genres. Similarly, Mauranen (2013, pp. 29–30) takes the case of science blogs to claim that rhetorical hybrids do not adhere to the formal scientific language conventions, but rather rely on "the informality and spontaneity of spoken discourse." Hybridisation aims to build credibility and trust, create proximity with their audiences and stimulate interest in scientific matters. Similar to blogs, other rhetorical hybrids such as TED-talks and YouTube science videos (Valeiras-Jurado & Bernad-Mechó, 2022) replicate the rhetorical information organization of existing genres, but disseminate science through plain, non-formal spoken language.

Although scientists are increasingly encouraged to use these digital genres to reach a wide audience, mastering public science communication effectively remains challenging. Producing digital spoken genres requires the use of digital tools and resources in order to create appealing texts supported by (audio)visual elements, as explained by Rowley-Jolivet and Carter-Thomas (2019) for the case of author videos, Riboni (2020) for vlogs, Vivas-Peraza (2022) for crowdfunding video pitches and Bernad-Mechó and Valeiras-Jurado (2023) for science videos. As the literature notes (Nieman, 2000; Roque, 2017), integrating multiple semiotic modes (visual, verbal and aural) makes oral texts more effective, which is key to participatory science genres such as citizen science projects (Reid, 2019).

Although creating texts with digital tools and dedicated e-platforms may be easily manageable (Quintana & Heathers, 2021), it requires multiple technologies to capture, edit and produce well-crafted audiovisual stories of science. Effective language (i.e., appropriate register and style) and multisemiotic meaning-making skills are also fundamental to creating rhetorically persuasive and impactful texts.

To address the multiple challenges posed by digital text composing, genre-based approaches advocate collaborative, multimodal composition tasks encouraging students to co-create digital texts using digital tools. These approaches cover not only general language learning purposes (e.g., Akoto & Li, 2025), but also language learning for professional purposes. For instance, Kang (2022) discusses how students utilize their essay-writing experience to produce a digital video clip for a broad audience, thereby developing their writing-to-speech and print-to-digital composing skills. Kang concludes that genre knowledge transfer supports digital skills development. Meanwhile, Dressen-Hammouda and Wigham (2022) engage their engineering students in the use of instructional video

[2] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=R%26D_personnel#Highlights.

tutorials to learn how to combine language and multimodal elements for composing digital texts. Beltrán-Palanques and Edo-Marzá (2024) also advocate the integration of language and digital skills learning and, as an example, they report on the use of clinical pictures and written and audiovisual versions of brief presentations of medical cases to teach effective doctor-patient communication. Overall, these genre-based approaches provide a robust foundation for developing general and professional language and communication skills.

1.3. Aim of the study

Building on our previous findings on digital written communication practices among women scientists (Pérez-Llantada et al., 2025), this study aimed to identify digital spoken communication practices. Our aim was two-fold: to uncover the potential barriers to engaging in such practices and to assess the specific language and digital communication training needs of those involved. As with our previous work (Pérez-Llantada et al., 2025), this research forms part of an ongoing European Commission funded project dedicated to developing solutions to address these training needs.[3] For this study, we posed the following research questions.

RQ1. Do women scientists engage in digital spoken forms of communication to share their work with a broad audience? If so, what contextual factors determine the extent of their engagement?

RQ2. What digital genres, tools and resources do women scientists use to share their work when engaging in these digital spoken forms?

2. Methods

2.1. Study design

This is a survey-based study, as described by Creswell (2014). We opted for this methodology because it enables us to collect data quickly and gain an overview of the phenomenon under investigation. It also allows us to generalize the findings from the sample population to the wider population and draw conclusions about the specific digital practices and views identified. We also opted for a survey design to collect cross-sectional data, i.e., at a time of rapid technological change, paving the way for future longitudinal studies.

In order to collect data on digital science communication practices, an online questionnaire was created. This questionnaire comprised 87 behavioural and attitudinal items concerning literacy and orality practices. The first section of the questionnaire was designed to identify the digital communication practices that respondents engaged in, as well as their professional and personal rationales/motivations for doing so. This section included categorical questions (e.g., '*Yes*', '*No*', '*No, but*' …), Likert-scale questions (ranging from 1 to 5 to gauge importance), and multiple-choice questions allowing for multiple responses. The second section focused on the genres used to communicate science. It employed similar question types to the first section. The third section used categorical questions to identify how the respondents used digital tools and resources to communicate science online. The questionnaire covered two domains of digital communication, both written and spoken, as this is the traditional division of domains in the field of specialized discourses. This approach enabled us to split the larger construct of digital communication into two meaningful sub-constructs —written and spoken—, and to conduct a more detailed and focused analysis of each of them. In previous work (Pérez-Llantada et al., 2025), we exclusively reported on the items that addressed digital writing practices. Here, we provide a separate analysis focusing exclusively on the 29 items of the questionnaire specifically relating to digital spoken practices.

This study is exploratory in nature, aiming to provide initial insights into digital spoken communication practices among women scientists rather than seeking rigorous statistical validation. As with those relating to digital written communication, the items relating to digital spoken communication do not constitute a formal, pre-validated sub-scale of the questionnaire. They were selected in line with this study's specific research focus and target sub-construct (domain) of digital communication. However, we took several steps to mitigate the risks associated with unreliable data. First, the items were selected based on the relevant genre studies on digital science communication, which provided a solid conceptual basis for validating the questionnaire. This approach also applied in earlier work (see Pérez-Llantada et al., 2022, Pérez-Llantada et al., 2025), resulted in a sufficiently robust and consistent survey instrument to obtain reliable data. Other steps to ensure reliability in the survey design included the use of clear, concise language, avoiding lengthy questions, and ensuring a logical (from general to specific) flow. We included a limited number of questions so as not to make the questionnaire too long. Our prior experience shows that this maximises participation.

Finally, the three co-authors reviewed the initial survey design several times to ensure consistency in the use of the terminology and maximise the comprehensibility of the items. During this iterative process, we checked for clarity, relevance and potential biases, resolving issues relating to question wording, respondent understanding, and the overall structure. Specifically, the review process resulted in the concepts being formulated more precisely and consistently (e.g., 'digital practices', 'digital tools', 'digital resources'). By clarifying what was being asked, we aimed to reduce uncertainty and increase the chances of uniform interpretation among respondents. We used Spanish, the working language of our target population, to guarantee clarity and understanding. In addition, we created an introductory text to accompany the questionnaire, explaining its thematic scope ('digital science communication').

[3] dilan4scientists.eu

To ensure research transparency and rigor, we also prepared a disclosure research data protocol for administering the questionnaire via email. This protocol was approved by an ethics committee (No. ref.: RAT 2023-183).

2.2. Population surveyed

We found that AMIT,[4] Spain was a convenient sample to survey women scientists across varied disciplinary fields (see AMIT database of women researchers and technologists). In the present study, we narrowed down the population to focus on women scientists in the biological and health sciences (BHS) fields. Compared to other disciplinary groups, this group was found to engage the most in public science communication (Pérez-Llantada et al., 2025). The selected cohort (n = 1690) was deemed sufficiently representative as it included both junior and senior scientists (34% had up to 10 years' experience, 36% had 10–20 years' experience and 30 % had over 20 years' experience). Besides, the majority of them had frequently (45%) or occasionally (49%) carried out public science communication (see Table S1. Demographic data on the population). We used these demographic data to speculate about the implications of the findings for researchers' training practices.

Although we were aware of gender discrepancies, this study does not adopt a gender-based perspective. Our objective was instead to explore women scientists' activity in the context of digital transformation. As the study only examined women scientists' practices in the fields of biology and health sciences, it is not possible to generalize the findings to other disciplines. These limitations will be addressed in future research.

2.3. Data analysis and interpretation

We collected 398 responses, representing a response rate of 23.55% of the surveyed population, and analyzed them statistically using SPSS 13.0.0. We calculated frequencies and percentages for questions with qualitative/categorical values (e.g., question type '*Yes*'/'*No, but I plan to do it in the future*'/'*No, and I don't plan to do it in the future*'). The Pearson Chi-square test was applied to these values, with Yates' correction or Fisher's exact test if necessary. We also calculated frequencies, medians and interquartile range (IQR) for items with ordinal quantitative values (i.e., a Likert scale from 1 to 5, where 1 indicates *not important* and 5 indicates *extremely important*). The ordinal component was used to identify the central tendencies of the ratings for these items. In both cases, the non-parametric Kruskal-Wallis test was used. When the Kruskal-Wallis test was significant, we ran multiple comparisons between categories or groups to determine which means were different and to estimate the degree of difference. The statistics were tested at a significance level of $\leq$0.05 (95 % confidence level).

As the population was stratified according to the types of research methodology used by scientists in the BHS fields (i.e., QUALitative, QUANtitative, or both QUAN/QUAL), this variable was tested to determine whether it was an explanatory reason why scientists engage in digital spoken practices. Additionally, we carried out correlation analysis to better understand respondents' use of digital tools and resources. This analysis enabled us to identify significant correlations and determine the causal relationships between the digital tools listed and

i) the way in which respondents composed digital spoken genres (whether individually, collaboratively, or both),
ii) the importance of these genres in respondents' professional contexts, and
iii) the importance that respondents gave to these genres.

We used genre and rhetorical genre studies (Miller, 2016; Swales, 1990, 2017) to interpret the main findings. We understand 'genre' to be a type of discourse with a set of communicative purposes and a specific intended audience. We also adopted other genre-related concepts such as 'genre repertoire' and 'discourse community' in order to interpret the group of respondents as a socio-rhetorical grouping primarily determined by functional factors, such as communicative needs and goals (Swales, 1990, 2017; JoVE, online). We also considered pedagogically oriented genre research when interpreting the findings, taking into account the role of genre knowledge transfer in digital composing. Finally, we used Miller's (2016) conceptualization of 'rhetorical hybrid' to discuss emerging forms of science communication online involving multiple semiotic modes operating simultaneously.

3. Results

3.1. Engagement in digital spoken communication practices

The data showed that nearly 60% of respondents engage in such practices as participating in webinars and podcasts or producing science popularization videos and educational videos (e.g., explainers, YouTube videos, and TED talks). A further 25% plan to do so in the future, resulting in a cumulative percentage of almost 85%. While this percentage remains below the extremely high level of engagement observed in traditional written practices, such as journal article writing, their engagement with digital spoken genres is comparable to that observed in certain written genres such as blogging and online science popularization articles and e-newsletters (Pérez-Llantada et al., 2025).

[4] The goal of AMIT (Asociación de Mujeres Investigadoras y Tecnólogas) is to achieve full and equal participation of women in the Spanish science system (as per https://amit-es.org/).

The methodology that respondents use in their research influences their level of engagement in digital spoken communication practices. Although there is no statistical significance when comparing the three groups, the tests reveal a statistically significant lower level of engagement in the QUAN group when compared with the QUAL-only and Both QUAN/QUAL groups (Table 1).

For 70% of respondents these digital spoken practices were *important/very important/extremely important* in their professional context. However, the observed statistical significance between the groups suggests that contextual constraints (e.g., research assessment policies similar to those reported by Tusting, 2018) influence respondents' level of engagement (Table 2). The multiple comparisons test confirms this hypothesis. Compared to the QUAL group, the professional context of the QUAN group gives less importance to these practices (with this difference being significant at the level of 0.017). Nevertheless, the fact that 38.2% of the respondents who use QUAN methods intend to continue doing so in the future suggests a changing trend.

Respondents rated digital spoken communication practices as fairly important. A total of 81.91% consider them to be *important/very important/extremely important*. Statistical analyses indicate that their views on these practices are not influenced by the variable 'type of research methodology' (Table 3). The absence of extreme outliers, as well as the homogeneous means and distribution of scores (SD and IQR) for each group, suggest that the variable 'methodology' does not influence their views.

For a large number of respondents, the webinar is the most *important/very important/extremely important* genre, in both their professional context and their own opinion (cumulatively accounting for 80% of respondents). Educational videos and science popularizations videos are considered less important in their professional context, with 40% of respondents rating each video type as important. However, in the respondents' view, these spoken genres are considered to be slightly more important (59.3% and 54.2% respectively). 50.25% of respondents also rated podcasts as *important/very important/extremely important*.

The 'type of research methodology' appears to influence how each spoken genre is rated, both professionally and personally. Statistically significant discrepancies are found between the three groups in relation to video abstracts, podcasts, educational videos and science popularization videos. Examining the p-values of the multiple comparisons reveals that, in a professional context, the QUAN group rates video abstracts lower than the Both QUAN/QUAL group (with a p-value of 0.004). The same is true for educational videos, which are rated lower than those in the QUAL and Both QUAN/QUAL groups ($p = 0.035$ and $p = 0.016$, respectively). The QUAN group also places less importance on science popularization videos than the other groups. The differences are significant at levels of 0.049 and 0.016, respectively (see Table S2. Importance of spoken genres in the respondents' professional context). The QUAN group also places less importance on webinars (0.015), video CVs (0.019), educational videos (0.021) and science popularization videos (Table S3. Importance of spoken genres in the respondents' view). No differences were found between the groups for video abstracts and podcasts.

3.2. Use of digital tools to communicate science

Respondents approach the production of digital genres in different ways. 62.80% and 56.69% of respondents participate in webinars and podcasts individually, respectively. Similarly, 61.11% create video CVs individually. Including those who responded 'Both individually and collaboratively', the cumulative percentages are 93.4%, 79.62%, and 87.04% respectively (Fig. 1). The nature of these spoken genres appears to constrain both the approach taken and the type of affordances used to compose them. Webinars, podcasts and video CVs involve individuals and require passive use of the materiality of the medium, i.e., an e-platform or an audio or video app.

As can be seen in Fig. 1, half of the respondents produce video abstracts collaboratively, while a further 31.17% produce them in both ways (giving a cumulative total of 81.17%). This predominant collaborative approach may be due to the fact that video abstracts are an add-on genre to online research articles. Writing articles involves collaborative co-authoring in the BHS fields. Collaboration also appears to extend to the creation of science popularization videos, with 44.35% being composed collaboratively and 34.78% being composed both collaboratively and individually. There are no significant correlations with the variable 'type of methodology', which suggests that the approaches to composing these digital spoken genres are similar, regardless of the research methodology employed by the respondents.

Overall, the use of digital tools and resources for composing digital spoken genres remains low. The low dispersion and standard deviation, as indicated by the error bars in Fig. 2, suggest that the community of respondents has not yet adopted multimodal genres for promoting scientific culture and socially responsible research online. However, the data indicate changing trends for the future. Fig. 2 shows that image, video and sound editing tools are used by almost 57% of respondents, with a further 25.96% planning to use them in the future. The lowest percentages correspond to AI tools for content or image generation (24.6%) and software for producing audio and video podcasts or videos associated with textbooks (17%). Here again, around half of the respondents plan to use these tools in future, giving cumulative totals of around 65% and roughly 60% respectively.

Almost 40% of respondents do not intend to use open multimedia resources (e.g., Pixabay and Flickr Commons) or software for composing audio and/or visual texts such as podcasts or videos to accompany textbooks. However, given that 30% of respondents use

Table 1
Engagement in digital spoken communication practices (categories grouped).

	TOTAL	QUAN methods	QUAL & both QUAN&QUAL methods	P_value
Yes	223 (56.9%)	40 (44.9%)	183 (60.4%)	0.006
No, but I am thinking of doing it in the future	100 (25.5%)	34 (38.2%)	66 (21.8%)	
No, and I don't plan to do it in the future	69 (17.6%)	15 (16.9%)	54 (17.8%)	

Table 2
Level of importance of digital spoken communication practices in the respondents' professional context.

	TOTAL	QUAN methods	QUAL methods	Both QUAN & QUAL	P_value
N valid mean (SD)	3.2 (±1.1)	3.0 (±1.1)	4.1 (±0.8)	3.2 (±1.2)	0.011
N valid median (IQR)	3.0 (±2.0)	3.0 (±2.0)	4.0 (±1.5)	3.0 (±2.0)	

Table 3
Level of importance of digital spoken practices in respondents' view.

	TOTAL	QUAN methods	QUAL methods	Both QUAN & QUAL	P-value
N valid mean (SD)	3.6 (±1.1)	3.4 (±1.1)	4.0 (±0.8)	3.6 (±1.1)	0.239
N valid median (IQR)	4.0 (±1.0)	3.0 (±1.0)	4.0 (±1.0)	4.0 (±1.0)	

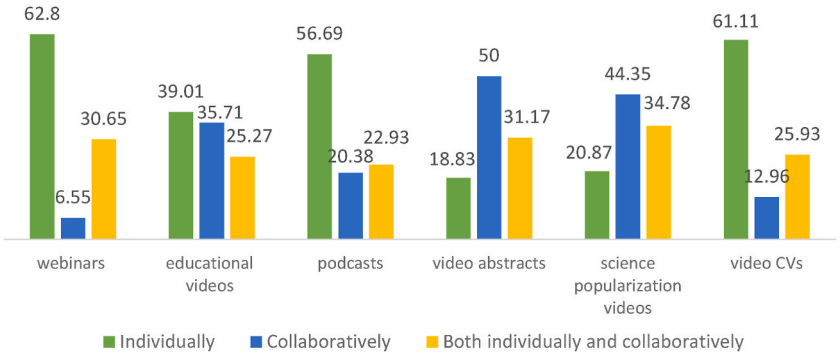

Fig. 1. Approaches to the production of digital spoken genres.

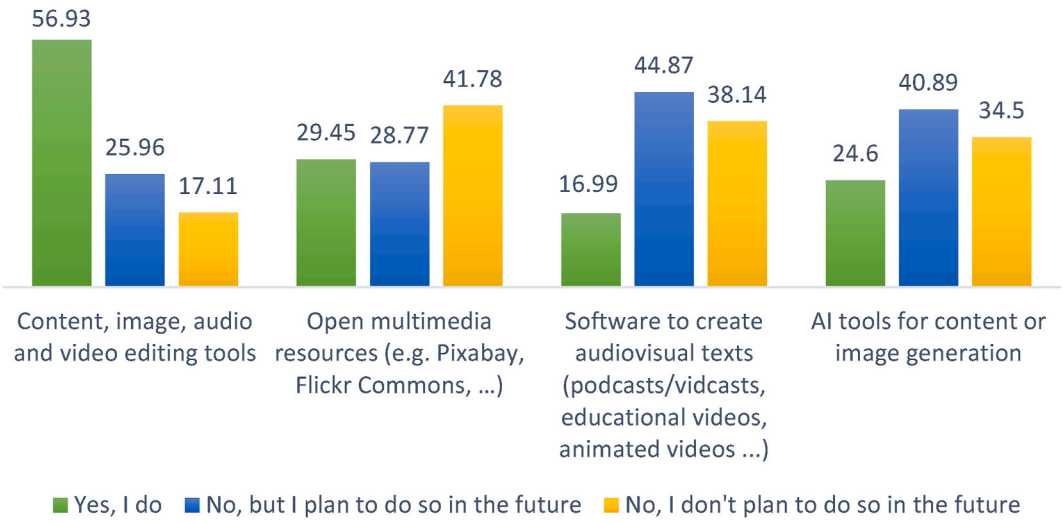

Fig. 2. Use of digital tools.

these resources and a further 30% intend to do so in the future, this trend may change. A similar trend is observed regarding the low use of AI, with around 40% of respondents planning to use it in the future.

The statistical analysis shows several strong correlations, suggesting causal relations between the use of digital tools and the importance of genres according to professional and personal contexts. Specifically, there is a strong correlation between the level of importance that the professional context attaches to podcasts, educational videos and science popularization videos and the use of content, image, audio and video editing tools. These correlations showed p-values of 0.035, 0.006 and 0.025 respectively for each of these genres (Table S4. Image/audio/video editing programs and importance of spoken genres in respondents' professional context). The post hoc multiple comparisons test reveals strong correlations between the use of these programs and the group of respondents for

whom podcasts and science popularization videos are important in their professional context (Table S5. Image/audio/video editing tools and importance of spoken genres by the respondents). Statistically significant associations were also found among those planning to use these programs in the future, with the importance given to educational videos varying by genre (0.031 and 0.020, respectively). The group that does not plan to use these tools rate them as less important. This difference is significant at the 0.038 level compared to the group that plans to use them.

Furthermore, respondents who place greater importance on video abstracts, video CVs and podcasts tend to use editing tools more frequently. Those currently using these tools, as well as those planning to use them in the future, place a significantly greater personal value on educational videos and science popularization videos (showing p-values of 0.004 and 0.002 respectively for educational videos, and 0.006 and 0.001 respectively for science popularization videos). The findings suggest a strong correlation between the groups that currently do not use these tools and those who do not intend to use them in the future, due to the lesser importance attributed to these video genres. Fig. 3 summarizes the causal relationships between the variables.

The use of open multimedia resources is strongly correlated with the importance assigned to video abstracts, podcasts, educational videos and science popularization videos in respondents' professional contexts (Table S6. Open multimedia resources and importance of spoken genres in the respondents' professional context). Greater use of these resources is statistically significantly associated with groups whose professional contexts attach greater importance to video abstracts and podcasts. There are also statistical differences between this group and those who do not intend to use these resources (0.006 and 0.026, respectively for each genre type). Moreover, the use of these digital resources is strongly associated with a group that places greater importance on educational and science popularization videos. This group differs significantly from those who do not plan to use the resources in the future, with respective p-values of 0.026 and 0.011.

A statistically significant association was also found between a higher the use of open multimedia resources and the greater level of importance given by respondents to video abstracts, webinars and video CVs (Table S7. Open multimedia resources and importance of spoken genres by respondents). The group that places greater importance on these spoken genres also plans to use these resources in the future. Significance was found when this group was compared with the group that does not plan to use these resources, showing an association with a lower level of importance given to these genres. The latter group values these resources more highly. Furthermore, the former group, which shows lower use of these resources, attaches less importance to educational and science popularization videos than the group that shows higher use (0.001 in both cases). Fig. 4 provides a summary of these causal relationships.

A strong correlation is observed between the use of software for creating podcasts or videos associated with textbooks, and the importance given to certain video genres in each professional context. The group that does not intend to use this software in the future is the one whose professional context places less importance on video abstracts, video CVs and podcasts. This is significantly different from the groups that intend to use it, or already do so. Both of these groups show greater use of this software. The differences between the three groups are significant for educational videos and science popularization videos (<0.001) (Table S8. Software for creating podcasts/videocasts or videos associated with textbooks and importance of spoken genres in respondents' professional context).

Correlation analysis confirms a positive relationship between the importance that respondents place on the spoken genres listed in the questionnaire and the extent to which they use the software. The differences between the groups are all significant at a p-level of <0.001. Those currently using the software and those planning to use it in the future place greater importance on video abstracts and video CVs. The group that uses this software for podcasts and educational videos shows a strong correlation with placing greater importance on these spoken genres. Finally, the group that attaches less importance to science popularization videos shows no plans to use the software in the future (Table S9. Software for creating podcasts or videos associated with textbooks and importance of spoken genres by respondents). Fig. 5 summarizes the direct causal relationships.

The use of AI tools for generating content and images also shows strong correlations between variables (Table S10. AI tools and importance of spoken genres in the respondents' professional context). Firstly, it was statistically corroborated that the group whose professional context placed less importance on video abstracts, podcasts and educational videos correlated with lower AI use compared to the group that does not plan to use AI in the future. Secondly, AI use is strongly correlated with the importance that respondents attach to spoken genres and science popularization videos (Table S11. AI tools and importance of spoken genres by respondents). The group that gives less importance to video abstracts and podcasts significantly correlates with lower use of AI tools compared to the group that plans to use them in the future (with significance levels of 0.036 and 0.005, respectively, for each of these genres) and the group that uses them (with significance levels of 0.040 and 0.005, respectively).

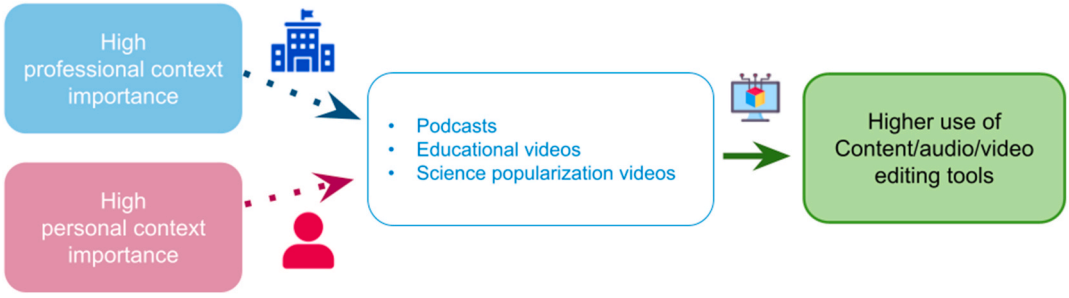

Fig. 3. Direct causal relations (content/image/audio/video editing tools).

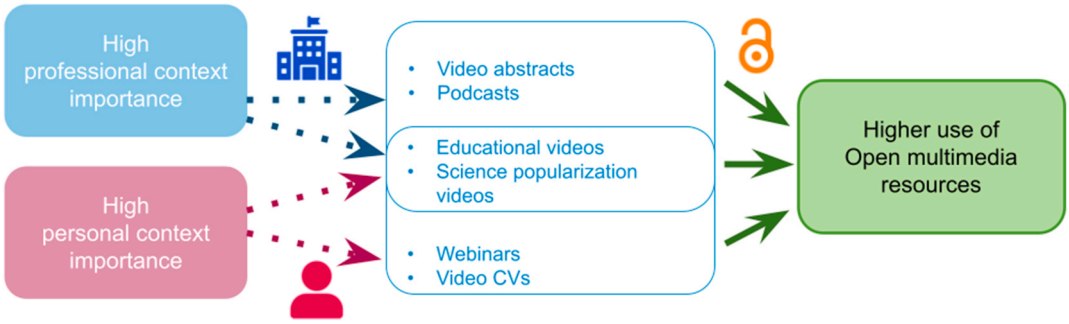

Fig. 4. Direct causal relations (open multimedia resources).

Fig. 5. Direct causal relations (audio/video software).

Furthermore, greater use of AI tools is strongly correlated with placing greater importance on educational videos and science popularization videos. Significant differences were observed between the group that showed greater use of AI tools and the group that does not plan to use them in the future (with $p = 0.007$ for educational videos and $p = 0.034$ for popularization videos). Fig. 6 summarizes the direct causal relationships found.

4. Discussion

This study explored the impact of digital transformation on women scientists' spoken science communication practices and their use of emerging digital formats. It also aimed to identify the use of the digital tools and resources commonly used to support these practices. The two key findings, namely the influence of the variable 'type of research methodology' and, on the other hand, the role of rhetorical hybrids in public science communication, are discussed below.

4.1. Science democratization online

Regarding the level of engagement of women scientists in digital spoken communication practices (RQ1), our study showed that the 'research methodology' variable did not influence the respondents' perceived importance of these practices in their professional context. The respondents' approaches to composing the digital spoken genres included in the questionnaire were also unaffected by this variable, showing consistent patterns across the QUAN/QUAL/QUAN&QUAL groups. However, the variable in question appeared to significantly influence their engagement in public science communication, with those using qualitative, unstructured data showing greater engagement.

This variable also impacted the level of importance given to specific genres, notably webinars, podcasts, video CVs, video abstracts, educational videos and science popularization videos. It can be surmised that qualitative data can easily be translated into plain language for non-expert audiences. However, the same cannot be said for quantitative, structured data, that is to say structured and tabulated data that can be counted or measured in numerical values, as defined by Creswell (2014). It should be noted, however, that the statistical differences found may be biased as only digital practices were considered. Respondents may also use traditional science communication formats, such as TV/radio, workshops or science fairs. Future research should determine which traditional or digital practices will become more prevalent in the future, and the extent to which research methods influence this across the disciplines beyond the biological and health sciences.

This study also tentatively suggests a potential discrepancy between current research policies and benchmarks for academic promotion, such as scientific publications, and the Open Science agenda, which promotes public science communication practices such as science outreach. This discrepancy may explain why, although the respondents rated certain genres of socially responsible research

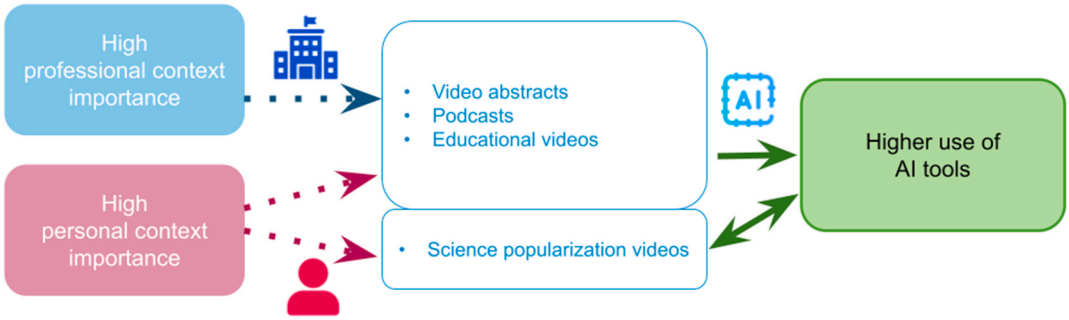

Fig. 6. Direct causal relations (AI tools).

(namely, webinars, podcasts, educational videos and science popularizations) highly, engagement with these was relatively low. The findings suggest that these practices were not accorded significant value within the scientists' professional contexts. This is also pointed out by Birch-Becaas and Reynolds (2024) in their comparison of French, Norwegian, Romanian and Spanish scientists, in which research outputs such as educational videos (YouTube, TED talks) are not highly valued.

Open Science promotes the democratization of science by encouraging scientists to communicate with a broad audience, including Internet users (Fecher & Friesike, 2014). An increasing number of our scientists are involved in using digital communication channels. In fact, more than half of them already use these channels and a further quarter plan to do so in the future. However, although there seems to be a growing trend in digitally mediated public science communication, our findings suggest a discrepancy between the values of the professional context and the scientists' current practices. According to our data, the digital shift appears to align with OS mandates that advocate an open scientific culture through dynamic publication formats combining text, visuals, and other multimedia elements to attract a sufficiently wide audience (Heller et al., 2014, p. 192). It is likely that scientists in the BHS fields, such as those we surveyed, may not engage fully in socially responsible digital communication because their professional interests must focus on scientific productivity, i.e., article citation counts. This corroborates Tusting (2018).

From the data we can also infer that the respondents' high valuation of webinars and other digital formats such as educational videos, science popularization videos and podcasts, may lead to increased engagement in digital spoken practices in the future. In line with Aksnes et al. (2019), we advocate for increasing the value of altmetric indicators in researchers' academic promotion processes. This could incentivize engagement, particularly among female researchers, in forms of communication that promote science for all. However, it is challenging to do so. As previously noted, outlets measured with altmetrics have limitations such as character restrictions and the absence of peer review. This makes it difficult to assess their true impact (Puschmann, 2014; Sugimoto et al., 2013; Thelwall et al., 2012).

It should be reiterated that our sample population did not include men and women, which restricts the validity of any gender-specific conclusions. As we mentioned previously, the questionnaire was designed to explore digital communication practices in the context of digital transformation only. On the other hand, the data gathered did not allow us to evaluate the extent to which participants were engaged in traditional forms of public science communication such as participating in TV and radio programs, workshops, school talks, or science fairs. These activities are considered to be socially responsible practices (Loroño-Leturiondo & Davies, 2018). Here, again, it can be hypothesized that these traditional forms are also constrained by the existing genre regimes (Tusting, 2018). If so, policymakers should consider increasing the value of altmetric indicators when measuring the social impact of research. This could incentivize traditional and digital public science communication practices. Currently, altmetrics are not as prevalent as the bibliometric indicators used in genre regimes. Future research should assess the perceived institutional recognition of digital spoken science communication practices. It should also ascertain the extent to which engagement in these socially responsible practices hinders the career development and research productivity of various groups of scientists (e.g., women and early career researchers).

4.2. The digital turn

According to genre theory, the communicative practices of a discourse community are built upon the use of genre repertoires (Swales, 1990). These repertoires offer rhetorical responses to social and rhetorical exigencies (Miller, 2016), in our case the demands of the OS agenda. With regard to women scientists' use of digital genres, digital tools and resources to share their scientific research (RQ2), this study provides evidence of increasing engagement with genres requiring digital tools and resources (e.g., content, audio, video editing software and AI tools for image generation) that align with the OS agenda (Fecher & Friesike, 2014). Furthermore, a significant percentage of respondents planned to engage with these genres in the future, which suggests that digital transformation is gaining momentum among the 70% of experienced researchers in our sample population who, according to the demographic data (Table S1), engaged in public science communication either frequently or occasionally. We can assume that their familiarity with traditional genres, and presumably with rhetorical hybrids too, will likely encourage greater engagement with digital spoken practices in the future.

In the questionnaire we intentionally included some hybrid genre forms (e.g., webinars and podcasts) that have been discussed in

the relevant literature on digital genres. We assumed that the respondents were familiar with the generic conventions of existing formats and that their prior genre knowledge would facilitate engagement with the new forms. This assumption was validated by the finding that the majority of respondents engaged with webinars, either individually, collaboratively or both.

The questionnaire also included other rhetorical hybrids combining verbal and aural modes with visual and auditory modes to communicate science to multidisciplinary, and wide audiences (e.g., video abstracts, explainers, educational videos, and science popularization videos). As with webinars, these genres have features of rhetorical information organization in common with the traditional lecture genre. We assume that these formats enhance prior genre knowledge by integrating elements and strategies of multimodal rhetoric typical of science communication (Nieman, 2000; Roque, 2017), enabling them to effectively reach multiple audiences.

This study also provides preliminary evidence of women scientists engaging with genres supported by digital tools and resources, such as content, image, audio and video editing tools and AI tools for image generation. A significant percentage of respondents also planned to use these tools in the future. Over half of our respondents communicated their science to non-expert audiences through various digital audio/visual formats. While this percentage could have been higher given the sociohistorical context of digital transformation, a further 25% planned to engage in digital communication more extensively in the future. We can therefore expect to see an increased use of digital spoken practices in the future.

Many emerging digital genres were in fact valued (very) highly by our respondents, regardless of their level of engagement with them. However, the data showed that traditional and advanced digital tools, such as AI, have not yet been widely adopted, despite respondents recognizing their importance. To support scientists' communication needs and increase science outreach in the BHS fields and other disciplines, one feasible response would be to provide training to raise awareness of digital communication tools to enhance their research work and spread more widely its social impact.

The set of genres identified in this study lends further credence to the ecological view of genres in digital media. Engagement with video abstracts, podcasts and science popularization videos indicates the existence of digital composing practices across related genres. For instance, consider the ecology formed by the research article and these add-on audiovisual genres. Other genre ecologies involving digital composing processes across content-related genres can also be identified, such as that of the video methods article and educational video textbooks (JoVE, online[5]). Although engagement in these genres could have been higher in light of the sociohistorical context of digital transformation, it is worth noting that a further 25% of respondents intended to engage more extensively with digital communication in the future. Based on our BHS respondents, it seems reasonable to extrapolate that scientists are increasingly 'accommodating science' to non-expert, lay audiences today. However, as this study only focused on the BHS field, future research should explore digital composing practices across spoken and written genres in other disciplines.

4.3. Study limitations and implications

The study findings have several implications that should be explored further in future gender research. Although more than half of our respondents engage with science online using digital tools, this only partially supports the previously reported gender imbalances, such as the low participation rate of women scientists on YouTube on compared to male scientists (Sugimoto et al., 2013). Nevertheless, it was significant that the respondents showed personal interest in audiovisual innovations for public science communication. This interest may trigger more active engagement in these forms of communication, potentially at the expense of engaging in journal article writing for research publication purposes. If so, this could lend weight to Aksnes et al.'s (2019) assertion that the research productivity of female scientists is lower than that of their male counterparts. Our study did not use a comparative gender design. Therefore, further insights into these trends could be offered by comparative gender studies.

4.4. Pedagogical implications

This study has important pedagogical implications for training scientists. Miller's (2016) argument on the nature of rhetorical hybrids provides a valid basis for proposing a genre knowledge transfer approach to training scientists in emerging digital forms of public science communication. As others have argued (e.g, Kang, 2022), a pedagogical approach to genre knowledge transfer could be applied to encourage scientists to become more aware of, and acquire, the skills needed to recontextualize specialized knowledge. One way of achieving this would be to teach them how to shift from specialized language to plain language. This requires the ability to transfer the skills acquired when using a formal scientific register to a non-formal, conversational register. The latter facilitates science communication between scientists and citizens (Reid, 2019).

Moreover, formal instruction on aspects of rhetoric and language can raise trainees' awareness of how knowledge of existing genres supports the composing process of digital genres. A research article, or shorter text, such as an abstract, can provide a starting point for learning how to apply recontextualization strategies to produce a podcast or videocast, a clinical picture talk or an educational video methods article, by re-using and re-adapting the content of the source text to make it accessible to a non-expert audience. Drawing on transferable skills could also be pedagogically beneficial to develop skills in register use, helping scientists become more familiar with and confident in discourse style strategies to communicate science online both formally and informally. As Mauranen (1993) notes, the

[5] JoVE See https://app.jove.com/es/textbook-mapping?utm_campaign=EMEA_ES_CS %20Textbook % 20Mapping_Q3 %202023&utm_medium=email&_hsmi=265099237&_hsenc=p2ANqtz-8CsCOx3SnGf8eSyXU78WEjs3MXUYBlzRiY-NGva9yIJCsFfHzesTR4OpfV6o8vrvrcRXpJfBVh6uJE9tNdHYSuEjxgEA&utm_content=265099237&utm_source=hs_email.

appropriate use of register styles in digital science communication is key to effective and persuasive communication. Zou and Hyland (2024) make a similar claim for explainer videos that recontextualize the content of their corresponding research article. We believe that the same is also true of the set of digital genres discussed in this study.

Integrating language with digital tools could enhance scientists' training in digital spoken science communication. Language learning tasks could incorporate digital tools for editing content, such as tools for creating pre-planned speeches or scripts for video-based genres, as well as tools for de-jargonizing scientific texts to make them more easily understood by non-expert audiences. Specific tips provided by leading publishers in the BHS fields could also be useful pedagogically. For example, the British Medical Journal's[6] guidelines for creating video abstracts include writing a script, and explaining the article content "in a way anyone could understand".

Following Dressen-Hammouda and Wigham (2022), we suggest instructional strategies to raise awareness of the rhetorical effects of multimodality and visual rhetoric in digital communication to effectively engage with diversified audiences. This instructional approach is relevant given that our respondents engaged with, or planned to engage with, genres combining verbal/spoken text and visual resources. Further, it can encourage scientists to compose genres with the help of digital tools. Additionally, it can offer ethical guidelines on how to generate spoken text and multimedia material through the ethical use of AI. In our case, the importance that the respondents attached to certain genres, editing tools, open resources, audiovisual software and AI tools means that these can be easily incorporated into pedagogical tasks. For instance, trainees could be asked to compose an explainer or a science popularization video. These two genres were consistently rated as being especially important. Conversely, if the aim is to meet the demands of the professional context, the focus of the instruction should be on podcasts and educational videos, given the importance that the respondents placed on these genres in their professional lives. These two genres showed strong correlations with the different digital tools and resources listed in the questionnaire. Needless to say, it is best for instructors to decide which genres to teach according to the specific needs of their trainees. Besides, the literature on digital genres emphasizes the importance of learning how to integrate multiple semiotic modes. Riboni (2020) points this out in relation to vlogs, as have others with regard to participatory science genres (Beltrán-Palanques & Edo-Marzá, 2024; Vivas-Peraza, 2022).

Formal training can be supplemented by situated learning. Earlier we noted that 30-40% of respondents composed the spoken genres listed in the questionnaire both individually and collectively. Learning within the community through collaborative composing practices also seems pertinent, given that half of the respondents in our study composed multimodal genres such as video abstracts and science popularization videos collaboratively. As Harrison and Loring (2023, p. 555) observe with regard to pubcasts, situated collaborative practices could enable scientists to communicate science online in a "more humanized" manner, promoting in the long term the democratization of science.

5. Conclusions

The primary aim of this study was to explore women scientists' spoken communication practices and their perception of the importance of such practices in relation to digital public science communication. The study revealed several contextual constraints on women scientists' participation in digital spoken communication practices. These constraints included a lack of institutional recognition and incentives, and limited time. A lack of training in digital and language skills were also perceived as major impediments to getting the scientists involved in these practices. Additionally, the study revealed that there is a preference for one-way communication models over more participatory models of Open Science (e.g., crowdfunding and citizen science). It is crucial that policymakers actively encourage scientists, particularly women, to engage fully in participatory models that promote democratic science. This can be achieved by addressing the discrepancy between the perceived value of digital forms among scientists and their limited involvement in participatory science communication. It may also redress the observed mismatch between policies and practices. Therefore, it is recommended that training be provided to scientists, especially women, in digital skills, communication strategies, and the use of technologies such as AI, with a view to optimizing science outreach. Specific training resources should be developed to cater for scientists' needs. Ways should be found to address the different level of engagement in public science communication that is associated with their research methodologies. This would benefit funding bodies and organizations seeking to promote participatory science communication models.

CRediT authorship contribution statement

Carmen Pérez-Llantada: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Data curation, Conceptualization. **Rosana Villares:** Writing – review & editing, Visualization, Conceptualization. **Oana Carciu:** Writing – review & editing, Conceptualization.

Declaration of competing interest

A disclosure research data protocol was approved by an Ethics committee (N[a] ref[a].: RAT 2023-183) at the University of Zaragoza and the Research Ethics Committee of the Autonomous Community of Aragon: CEICA at the Aragonese Institute of Health Sciences (IACS).

[6] BMJ Author Hub.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.system.2025.103832.

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