Thinking outside the box: Senior scientists' metacognitive strategy knowledge and self-regulation of writing for science communication

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Abstract: Academics are increasingly engaged in writing genres with purposes and for readers outside of academia—a variety of science-based communication practices that fall under the term *science communication*. These practices often span different modes, genres, and even languages, requiring high degrees of rhetorical flexibility, strategic knowledge, and regulation of writing. In this study, we probe the self-regulation and specifically the metacognitive strategy knowledge (MSK) of seven senior scientists who regularly and actively engage with writing for science communication. We argue that understanding their MSK can illuminate how strategic knowledge is transferred across written genres, and importantly offer useful insights for the training of future scientists. Using data derived from in-depth, narrative interviews with a recall component, we identify a variety of strategies for task conceptualization/analysis, planning and goal setting, monitoring, and evaluating the writing of different genres. Task analysis appears particularly crucial in science communication writing, due to the great variety of purposes and readers that fall under this umbrella. Interestingly, our participants underscore storytelling strategies, and seem to transfer language and style monitoring strategies to and from science communication and publication. We map the strategies identified and discuss the implications of our study for further research and science communication pedagogy.

Keywords: Science dissemination, popular science, metacognition, writing regulation, scientific writing

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1. Introduction

Academics, especially in the sciences, are increasingly pressured to share their research with a variety of social actors (Defazio et al, 2020), through a variety of genres loosely comprised under the umbrella term of *science communication*: writing and other forms of communication of scientific knowledge for non-academic purposes (cf. Bucchi, 1996). In EU and in Sweden especially, this task has been crystallized in various laws and policies both at the national and the university level (Hetland et al., 2020). Undeniably, this push towards dissemination may reflect neoliberal, managerial ideologies framing knowledge as a commodity and the university as provider of a service—to the detriment of democratic values and theoretical excellence (Watermeyer, 2016). However, it is also undeniable that many academics engage in science communication because they want, rather than must (Davies, 2020), albeit perhaps with differing perspectives about its value (Perrault, 2013).

Although science communication is a broad umbrella, comprising different multimodal channels (Renwick et al, 2020), writing for science communication features prominently in modern academic jobs. Not only are scientists accomplished writers (Emerson, 2017), but they also increasingly produce a wide variety of genres for readers and purposes beyond academia (Luzón & Pérez-Llantada, 2019; Pérez-Llantada, 2021a,b).The question arises then of how best to prepare future scientists for these writing tasks. Raising scientists' awareness of the rhetorical dimensions of science communication and how these manifest implicit perspectives about its value in society is especially important since, as rhetorician Jeanne Fahnestock (2020, p. 376) points out, scientist themselves are increasingly skeptical about the "science of science communication" as it seems to promote an approach that results in short training sessions with inadequate focus on rhetorical and textual development. Additionally, Fahnestock (2020) strongly questions these approaches' effectiveness in promoting science communication writing that addresses readers as *audience for an argument* (p. 381), i.e. citizens capable of rational argumentation. To this end, understanding the practices of senior scientists with experience in science communication writing can be a first step, providing an emic perspective of how established academics approach this writing and adapt their strategies to address readers outside the academic sphere.

Probing senior scientists' strategies for writing science communication is also grounded on the idea that expert writers can adapt strategies to adjust content, rhetoric, and linguistic choices across situations. Theories of writing expertise from cognitive science (Bereiter & Scardamalia, 1987; Flower & Hayes, 1980; Kellogg & Whiteford, 2009) to applied linguistics and rhetoric (Beaufort & Iñesta, 2014; Cheng, 2007; Tardy et al, 2020) converge on the fact that writing expertise entails a strong metacognitive and self-regulatory component, especially when writing requires the construction of advanced knowledge for different readers and genres (Devitt, 2015; Castelló, Iñesta & Corcelles, 2013). Tardy and colleagues (2020) for instance conceptualize metacognition as a facilitator of genre knowledge transfer across situations and languages, and similarly empirical research underscored that metacognitive knowledge catalyzes the development and transfer of sophisticated writing knowledge across conditions (Driscoll et al. 2019; Kang, 2022; Kessler, 2021; Negretti 2021, Wei, 2020).

Specifically, the capacity to flexibly (re)construct scientific knowledge required in writing for science communication prompts the investigation of skilled writers' metacognitive knowledge about writing strategies—metacognitive strategy knowledge (MSK). MSK relates to the strategic and socially sensitive components of writing expertise, being "verbalizable knowledge about disadvantages and advantages of specific strategies regarding task characteristics. The question is then how senior scientists who regularly engage with science communication use their MSK to self-regulate their writing in genres that span a variety of readers and purposes, beyond academia. While these writers' knowledge may be at least in part implicit, as is often the case for capabilities matured via experience rather than training (Eraut, 2000; Polanyi, 1966), the verbalizability dimension of MSK may elicit and illuminate useful procedural dimensions in science communication, since it includes knowledge about "why and when those strategies should be used to complete a task successfully." (Karlen, 2017 p. 63). MSK is key for self-regulation: skillful writers can metacognitively regulate their strategies as required by the task (Harris et al., 2010, Wenden, 1991; Zhang & Zhang, 2019). Moreover, Karlen (2017) suggests that "to understand why some writers self-regulate their writing process successfully…, it can be helpful to take a closer look at their metacognitive strategy knowledge (MSK) about the writing process" (p. 62) and its role in self-regulation (SR) across the three phases of SR described by Zimmerman and Moylan (2009): forethought, performance, and self-reflection.

As part of a larger project aiming to illustrate the complex practices and experiences that fall under science communication, including scientists' motives, goals, and learning trajectories (Negretti et al., 2022), in this study we explore specifically how senior scientists self-regulate their writing for science communication, narrowing the focus on MSK, similarly to studies on academic writing (Karlen, 2017; Karlen & Compagnoni, 2017; Sala-Bubaré et al., 2021; Qin & Zhang, 2019). We maintain that an investigation of the nature of MSK held by these writers can provide crucial insights about how strategies are transferred and adapted across genres, as well as valuable input for future research on science communication training for novice scientists. Research shows for instance that early-career researchers seldom feel confident about their writing skills, either for publication or science communication (Mason & Merga, 2021). Promoting metacognition, and specifically MSK in science communication writing, can help novices manage the process of writing and raise their critical awareness of their own mental models of science communication, as resulting in rhetorical choices and stance (Perrault, 2013). A key contribution of this paper is thus a description of MSK in expert science communication writing. We pose the following questions:

1) What is senior scientists' metacognitive strategy knowledge (MSK) of writing for science communication, and what strategies do they use?
2) How do they self-regulate (SR) their writing for science communication?

2. Theories and research

The following theoretical synopsis will underscore the areas of alignment among theories from different fields that lead us to propose the focus on MSK.

In cognitive science, theorizations of writing expertise proposed by Bereiter and Scardamalia (1987) and Flower and Hayes (1985), emphasized the cognitive, procedural and social dimensions of writing. Specifically, Flower and Hayes (1985) posed that expert writers skillfully adapt their strategies to each rhetorical situation, adjusting what, how and why to address different rhetorical problems. Similarly, in scientific fields, developing expertise is "an act of learning where there is a dynamic between the content being addressed and the rhetorical requirements of the writing task." (Yore et al., 2002, p. 674). This conceptualization of expert writers has found wide support in further theorizations of writing, framed as a fundamentally metacognitive process (Hacker, 2018, see also Wenden, 1991, 1998). Expert writers are described as knowledge crafters (Kellogg & Whiteford, 2009), who can deploy strategies to adjust content in anticipation of readers' reactions (Galbraith & Baaijen, 2018).

In applied linguistics, and especially in rhetoric and L2 research on academic writing, theories have equally emphasized the multicomponent nature of writing knowledge (Cumming, 2020), and the importance of developing rhetorical flexibility and genre awareness (Cheng, 2007; Devitt, 2015; Swales, 1990). In L2 writing, the seminal work by Wenden (1991) established the importance of metacognitive, strategic dimensions of language learning, and has been followed by extensive research underscoring the strategic and self-regulatory dimensions of learning to write (Qin & Zhang, 2019; Zhang & Zhang, 2019). In genre studies, theorizations of writing expertise also emphasize its multifaceted and strategic nature and explicitly include metacognition in their model (Beaufort & Iñesta, 2014; Tardy et al, 2020), as important for writing development and to facilitate transfer or recontextualization of writing knowledge across situations and languages.

Thus, the theories summarized above converge on the fact that expert writers are skilled at regulating and adapting their writing process in response to rhetorical and situational changes. They are metacognitive about task conditions, their own knowledge of written genres, communicative goals, and strategies, knowing how and why to utilize them. This characterization aligns with the view that experts are better than novices at metacognitively assessing eventual problems and re-adapting their strategies across changing conditions (Zimmerman & Moylan, 2009).

Research has provided support for this characterization of writing expertise, connecting it to metacognition and self-regulatory dimensions (Castelló et al., 2013; Graham et al., 2013; Harris, 2010; Sala-Bubaré & Castelló, 2018; Sala-Bubaré et al., 2021, Zhang & Zhang, 2019). Additionally, research on writing knowledge transfer, recontextualization of genre knowledge, and rhetorical effectiveness has provided evidence that metacognition—especially conditional metacognitive knowledge of strategies and task demands—helps learners to adapt their writing across situations, rethinking rhetorical strategies, language, and content in response to anticipated desired outcomes and readers' expectations (Driscoll et al., 2019; Kang, 2022; Kessler, 2021; Negretti & McGrath, 2018; Negretti 2021; Roderick, 2019; Wei, 2020).

In the case of academic writing, this strategic ability requires not only adaptation to the immediate situation and genre, but also the awareness that different types of scientific genres share characteristics and features, forming constellations (Swales, 2004): strategies may be used and adjusted *across* genres. Traditional central scientific genres such as the research article share several content elements and rhetorical features with other corollary sub-genres, such as authors' bios, scientific blogs, and social media posts (Perez-Llantada, 2021a,b). Experienced writers, who often have evolved their genre knowledge through interaction and participation in a scientific community (Florence & Yore, 2004), are more skilled than novices at adapting and recontextualizing their genre knowledge across these constellations of related genres.

At the same time, scientific writing and science communication serve different purposes in society (Davies, 2020), and scientists themselves may hold different perspectives about its purpose and their own motives for doing it (Negretti et al., 2022). As Perrault (2013) described in relation to the PEST and CUSP[1] models of science communication, while some researchers may conceive science communication as a means to reinforce the (unquestionable) role of science in influencing society, other scientists may instead embrace views where science is inherent to a democratic society, and thus "combine appreciation for science with the kind of critical analysis that characterizes good scholarship, as well as good critique" (p. 4). In Sweden specifically, where our study was conducted, science communication has been promoted in law since 1977 (Bragesjö et al., 2012). However, previous research has concluded that scientists still experience barriers preventing them to engage in science communication and include it in their academic scholarship (e.g. Bohlin & Bergman, 2019; Cervin-Ellqvist, 2022). These barriers include a lack of recognition in promotion and recruitment processes, lack

[1] PEST: Public Engagement with Science and Technology, CUSP: (Critical Understanding of Science in Public (See Perrault, 2013, for a discussion)

of time, and training (Bohlin & Bergman; Dryler et al., 2022). Therefore, while strategies for transfer and recontextualization may not be straightforward, a metacognitive focus may help raise critical awareness of how different perspectives on science communication result in specific rhetorical and linguistic choices.

MSK, as the verbalizable component of metacognitive awareness—including the knowledge of why some strategies may or may not be suited for the task at hand—provides a way to examine the socio-cognitive connection between academic writing and other related sub-genres pertaining to science communication. Research has underscored MSK's role as a regulatory mechanism in learning and as a characteristic of effective writers (Karlen, 2017; Karlen & Compagnoni, 2017; Qin & Zhang, 2019). A focus on MSK helps understand how senior scientists engage with the contextualized nature of writing, choosing and adapting strategies based on task conditions and the rhetorical situation, and the "ethical, philosophical and social dilemmas" (Ampollini & Bucchi, 2020, p. 466) that science communication must address.

3. Method

3.1 Context and participants

We combined purposive sampling and snowball sampling (Russell Bernard, 2013) to identify participants with extensive experience of the phenomenon under study—written science communication. We first selected a pool of scientists based on a preliminary study, and then identified additional potential participants by asking colleagues, until no new suggestions were made. After shortlisting sixteen prospective interviewees, we invited them via email.

Seven scientists agreed. All were tenured senior academics in different STEM disciplines, with extensive experience in writing for science communication. All but one had written opinion pieces (*debattartiklar* in Swedish) in national/local newspapers or magazines, and all had either posted about scientific topics on social media/internet, written popular-science texts, or authored other types of scientific-based genres in trade magazines.

The interviews procedures adhered to the ethics recommendations of the Swedish Research Council and GDPR requirements—approval by an ethics committee was not required. Participants were given full disclosure about the study and signed an informed consent form prior to the interview, emailed to them in advance together with the background questions and the interview protocol.

3.2 Data collection and analysis

The data presented here is a cross-section of narrative interview data (Barkhuizen, 2015) collected in an ethnographic interview study on science communication, investigating scientists' personal experiences with science communication in a broader scope. Participants were asked to bring to the interview 1-3 examples of written science communication they produced, which were used to facilitate the recall and accuracy of the participants' retrospective account (Gass & Mackey, 2000). Retrospective qualitative accounts are appropriate to elicit metacognitive knowledge of strategies (Karlen & Compagnoni; 2017; Ohtani & Hisasaka, 2018; Zimmerman & Moylan, 2009). Interviews and similar data collection techniques "lead learners to retrospect upon their learning . . . requiring them to draw upon their *stored* metacognitive *knowledge* about learning strategies" (Wenden, 1998, p. 519).

To capture MSK and other dimensions of SR, we designed some of the questions in the interview protocol (Appendix A) to elicit the participants' MSK along the three phases of SR in Zimmerman's model (Fig. 1, Zimmerman & Moylan, 2009): metacognitive knowledge of Forethought strategies, of Monitoring and Control strategies; and metacognitive knowledge of strategies for Self-reflection and Evaluation.

Specifically (Table 1), Question 3 and 4 elicited task analysis, outcome expectations, task interest/value, and goal orientation. Question 5 and 6 targeted planning and goal setting; Question 7 focused on monitoring, and Question 8 targeted Self-reflection. As relevant to MSK, we also elicited their specific strategies regarding language (Question 9), and potential metacognitive knowledge of personal strategies (Question 10).

Answers to these questions were compiled into a grid corresponding to the SR phases in Zimmerman and Moylan's (2009) framework, and then analyzed. Note that since SR is both cyclical and multifaceted, boundaries between phases may be fuzzy (Pintrich, 2000, p. 455), posing challenges in distinguishing whether a strategy pertains to forethought or performance, for instance. In coding our data, we primarily followed the categorization embedded in the design of the interview questions (see Table 1), and withing these frames worked inductively through a constant-comparative approach (Miles et al., 2014) to identify themes summarizing the participants' description of strategies. We worked individually and then compared our interpretations to consolidate themes and compile a set of relevant quotes. Throughout, we kept analytic memos and a collaborative analysis log to ensure that our interpretation was recorded and systematic.

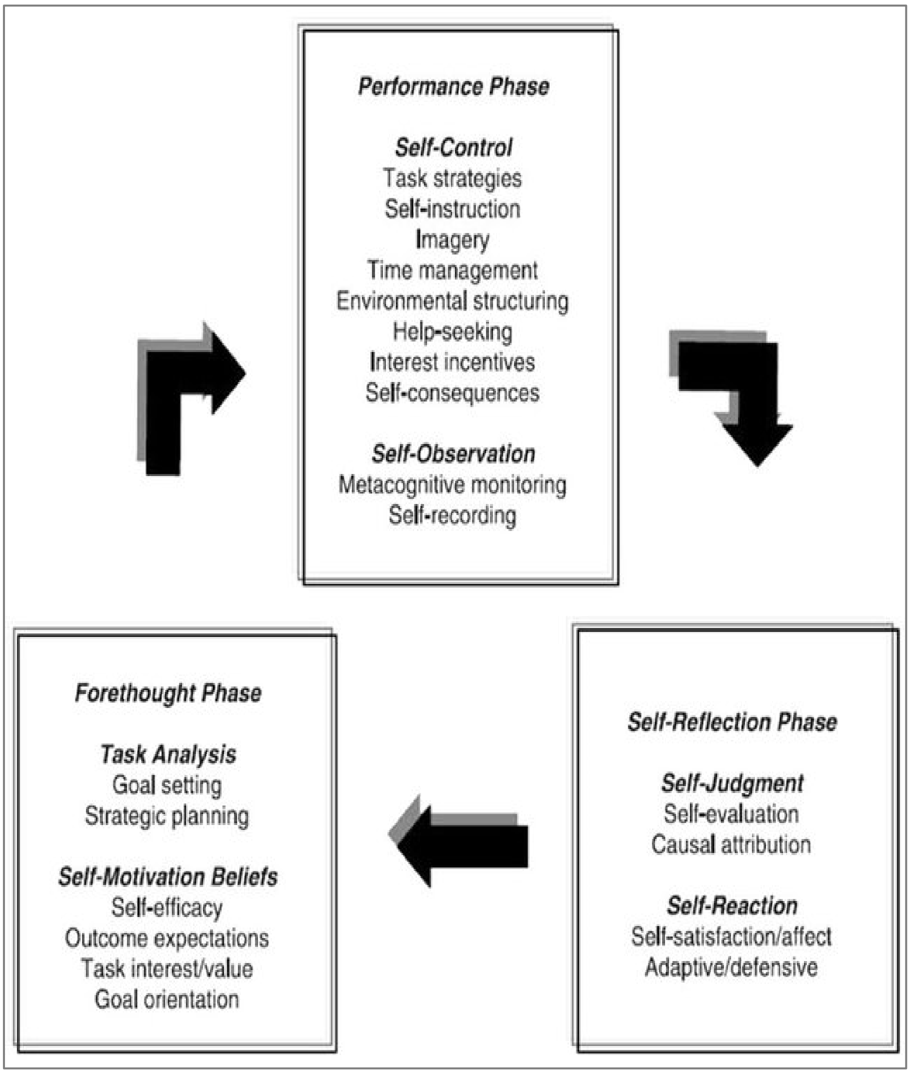

Figure 1: A cyclical phase model of self-regulation, Zimmerman & Moylan, Handbook of Metacognition in Education, Taylor & Francis Group © 2009. Reproduced by permission of Taylor and Francis Group through PSLClear.

Table 1. Interview protocol questions eliciting SR and specifically MSK.

Target MSK component/Phase of SR	Interview protocol question (with follow-up questions)
Forethought Phase	Referring to the texts selected as examples of science communication: 3. Can you describe the story of these (1-3) examples that you brought to the interview? What motivated you to write them? Are they connected to scientific articles or other published work? 4. How familiar are you with these genres/type of text? Comparing scientific publication and public communication genres like these, what are the differences and similarities that you see across these types/genres? 5. How did you prepare before writing these texts? 6. Could you tell us concretely how you started the process of writing?
Performance Phase	7. As you were writing the text, can you describe the process of writing these texts? Did you have any specific strategy in mind, for instance?
Self-reflection Phase	8. How did you know that you were done? How did you evaluate your final outcome?
Metaknowledge of language-specific strategies and personal strategies	9. How does language (Swedish or English) play a role in your writing this type of texts? 10. How has writing these texts given you an insight into yourself as a writer?

Note: The question numbers correspond to the numbering in the interview protocol (Appendix)

4. Findings – MSK and SR in writing science communication

We present the participants' MSK as corresponding to the three phases of Zimmerman and Moylan's (2009) SR model (Fig. 1): Forethought, Performance, and Self-reflection.

4.1 Forethought – task analysis, goal setting, and strategic planning

Forethought concerns task analysis processes, strategic planning, and sources of self-motivation. Task conceptualizations—task analysis in Zimmerman & Moylan (2009)—are fundamental for MSK: during forethought, activation of metacognitive knowledge about the task leads to strategic planning. In our interviews, we thus premised questions about strategies with questions eliciting task perceptions (see Table 1 in section 3.2), asking our participants to comment on their self-selected examples of science communication.

These examples showed considerable variety, illustrating the span of genres that may fall under science communication, as seen in Table 2 below.

Table 2. Participants' self-selected examples of science communication

Participant	Type of texts selected as example of science communication
R2D1	Professional guidelines (book), Chapter in popular science anthology, Trade magazine article.
R2D2	Non-fiction popular science book (2 examples)
R2D3	Op-ed (in Swedish: *debattartikel*) in national newspaper (co-authored), Interview, Trade magazine article
R2D4	Non-fiction popular science book, op-ed in a national newspaper (co-authored)
R2D5	Op-ed in national newspaper (rebuttal)
R2D6	Written science-based public project (co-authored), op-ed, Report
R2D7	Magazine article, Debate/op-ed in national newspaper, op-ed (rebuttal)

While some are well recognized genres (opinion pieces and popular science books), some pertain to genres that are partially "occluded" to the public (Swales, 1996) and are not easily categorized. The trade magazine article for instance is very much tied to the professional community it targets, while reports often aim at policy makers or industrial partners. The distinction in purpose among different genres is not clear-cut, as R2D6 comments:

> "Reports are both scientific communication, between scientists, and science communication, because they are read—I hope—also by experts outside academia, even if not the general public" (R2D6)

This quote also illustrates a main finding in our study: all our participants displayed metacognitive knowledge of the unique conditions posed by different science communication genres, which were often characterized relative to academic/scientific genres. Specifically, task analysis focused on the *purpose* of the genre, and translated in *two goals: a) to convey science, and b) tell a clear story*.
First, in terms of content, writing for science communication clearly aims at *conveying scientific knowledge*. However, while the content needs to be anchored to a solid scientific basis, the purpose is clearly different from academic publication. For example, R2D3, based on their own scientific work, writes to affect public opinion and policy makers (task value, goal orientation):

> "This has a strong connection to my previous research; the idea was to send out something about (topic of public debate) that has been going on for long, to point out that (specific approach) is counter-productive according to all research … the similarity is that research is needed for both [laughs] You know, you really need to know your subject and know about the field" (R2D3)

R2D6 also emphasizes scientific expertise, as does R2D2 who plans by reviewing existing evidence (a strategy common to academic writing):

> "Yes, absolutely the first example builds on a scientific publication … it is almost a way to apply the science." (R2D6)

> "Finding the right (material) … It means that one has to do one's research beforehand also for these things" (R2D2)

As mentioned, while the content is scientific, the purpose is quite different and may not tie closely to their research activities/publications. R2D1, R2D2, R2D4 and R2D5 comment that rather than disseminating their own scientific work, they aim to provide insights to professionals, educate, stimulate thinking, and correct inaccurate information in the public debate:

> "We have written some anthologies like small popular science chapters. They maybe don't give any guideline, but insights … I was part of the editor team and we pushed the authors to write these chapters together with their project partners" (R2D1)

> "There is some current research in them (books), things that I do myself or that colleagues do. But it is very much geared towards the general education purpose" (R2D2)

> "The (connection to their scientific work) is not super strong, but is more 'what is significant to think about in relation to such a scientific breakthrough?'" (R2D4)

> "I have done research about (topic), but these pieces do not come directly from an academic text … I read this opinion piece and I thought 'this is wrong' and so I wrote a rebuttal… that was also in response to an opinion piece that was basically b*s*" (R2D5)

The other key *goal* of science communication is *rhetorical*: *conveying a clear message, constructing a good argument, and telling a story*, functioning as starting points for writing. Storytelling and attention to literary qualities were connected to scientific publication, leading to specific rhetorical and stylistic strategies (R2D3):

> "You have to tell a story, but that you have to do in a scientific publication too … you can't just stack results on top of each other" (R2D2)

> "The biggest difference is that in a scientific article you can be more detailed, you can discuss issues with your research, you can go deeper into things, while popular science needs to be a bit more generalized and a bit more concretized. … You must be clear and precise in a completely different way." (R2D3)

Conveying a particular *message* was a clear goal for other participants as well, and had a particularly central role in writing rebuttals in ongoing national debates:

> "So that is the first thing [I think about]: 'What is their thesis? What is my main counterargument? ... Who are they [who wrote the original piece]?" (R2D5)

> "The first step is that we discuss: here we should make a contribution to the debate, because here we have something to add." (R2D6)

> "I reacted to a debate… I just got an idea and thought: 'Yes, [the rebuttal] should have this message'" (R2D7)

The goals described were clearly translated into strategic planning. The quotes below also highlight the *task interest/value* in writing for science communication:

> "Among the first things I think about is: What is the message in one sentence? … The rest of the text is all about explaining why this message is correct and why it is important… The introduction is an expansion of the title and is like a short summary, three sentences: I write that quite early and rewrite it a lot, because it sets the frame." (R2D7)

In terms of specific strategies, answers varied depending on the genre our participants were describing. In other words, our participants focused on *what was contextual for each type of text when planning their writing* (conditional knowledge). For example, R2D1 thought about strategies aimed at immediately catching the attention of the reader, while R2D4, writing popular science books, planned by thinking about the book in their head for a long time:

> "Catching the attention is good … what is the punchline? … You start with the part that catches the attention, some questions or something like that" (R2D1)

> "There is a long preparation process in my head…. When I actually start writing, it is very straightforward. … I don't write a lot of outlines or similar; it happens very much inside my skull." (R2D4)

Strategies aimed at *planning the structure for the text* were common (whether mental or on paper). Some of our participants described making a rough "skeleton" and how to adapt the structure to the constraints of the genre:

> "I really do the skeleton first." (R2D5)

> "I always think in a very structured way when it comes to these kinds of texts, that are extremely short… for example you can't have more than three points in that kind of text. I think about those things quite carefully before I start writing" (R2D7)

Interestingly, for *co-authored articles, strategies seem to suggest an element of social regulation* (Hadwin et al., 2018)—forethought entails discussions about the topic and the message:

> "We were so many people, and we had slightly different starting points on the question: 'How do we bring forward everything we think is important?' we had to reconcile this into one thought. … We discussed to arrive at what we wanted to say, and then we created like a skeleton or a structure. Then it went around to everyone in the group." (R2D3)

> "I have never written any [opinion pieces] all by myself… the first step is that there is a discussion … these discussions are brought up several times [before deciding to write something]" (R2D6)

Remarkably, our participants were quite confident when talking about their strategies, suggesting self-efficacy. This was attributed to their long experience as scientists as well as writers. For example, R2D5 described how their confidence about writing these types of texts was built over time through experience, and indeed transferred to their academic writing:

> "I have written a lot and for a long time … Lately I have done less, but I have developed my academic writing to be a little more pointed. There is something similar in writing science communication: make three points that converge towards the same argument" (R2D5)

Moreover, R2D6 suggests additional motivations than the wish to convey scientific knowledge, connected to enjoyment and self-satisfaction:

> "I feel more at home writing opinion pieces and reports than to write scientific articles. [laughs] It is closer to my everyday language … Scientific articles have their rules you know… So [writing science communication texts] has been easy for me." (R2D6)

4.2 Performance phase (monitoring)

The performance phase includes both monitoring and control strategies. As illustrated in the previous sections, these strategies are closely tied to task conceptualizations and genre: purpose of the text and target audience.

In monitoring, a common strategy concerned the *transfer of information from academic/scientific genres to science communication genres* such as reports and opinion pieces, considering their different purposes. Our participants clearly related what they write for publication with science communication genres:

> "a popular science article can be like a synopsis from a scientific article, so it can be more or less kind of the same" (R2D1)

> "This [webpage] builds on a scientific article I published on how to calculate [topic]" (R2D6)

> "We had an article published in [major scientific journal] so we realized we had a platform and we could be successful in conveying this knowledge to the public in a major national newspaper, the biggest debate forum in Sweden" (R2D7)

However, this process of *transfer* from scientific publication goes beyond content, and encompasses *strategies typically used in academic writing* to monitor accuracy and informativeness, for instance the scrutiny of existing research:

> "We prepared (to write an opinion piece) by reading all the previous research on this topic so that we realized what we wanted to include and built a structure" (R2D3)

The transition from a research article to a science communication genre can however be challenging and unsuccessful:

> "We wanted to disseminate this report and we thought of writing an opinion piece for a national newspaper, but basically only did a simplified summary and did not have a clear message. It did not work. The language was too dry and academic, and it did not have any argument. It is not enough to just do a summary, you need to dare to try to do it in a different way." (R2D6).

Challenges are tied to the need of having a clear message/story, requiring special *monitoring of the narrative* and careful editing of redundant parts. *Narrative as a form of argumentation is a rhetorical strategy that can in turn become useful in scientific publication*:

> "You need to tell a story, and it needs to be a scientifically valid story at the same time. There is so much more to think about when you write popularized science" (R2D2)

> "Everything in an article needs to contribute to this story. Imagine if you write a detective story and then you start writing about something else… so I use these kinds of ideas as well, a literary way of thinking when I write for publication" (R2D5)

Regarding control strategies, some participants described *personal approaches to structuring a science communication text*, especially in terms of argumentation: these strategies were typically developed over time from experience. For example:

> "I think both about language and structure when I write, although often the structure is quite worked through when I start writing. … When you're going to talk about why something is important, the order can be a little difficult because A motivates B and B motivates C and C motivates A. It sounds like I'm describing circular reasoning here, but it is more about having a coherent context of ideas." (R2D4)

> "It's a matter of practice and about developing processes for your writing… When you write for a broader audience you have to think quite differently and you need to simplify the language and minimize the use of technical terms. … What is difficult is to write about is causal links and complex contexts." (R2D7)

The quotes above show that in addition to monitoring the message and the story, two additional strategies emerged as relevant for regulating the writing process: *anticipating the readers' potential response,* and related to that, *strategies concerning language and style*:

> "I write for an educated public, and I definitely think about who will be reading." (R2D5)

R2D3 describes how they investigate the audience in order to anticipate its expectations:

> "I do some research to understand who my reader is. I call the editor and ask: 'Hi, who reads this newspaper… what is the scope or what is the target group', so that I can also put myself in the right mind for their expectations." (R2D3)

As shown by some of these comments, appealing to readers is also a matter of *monitoring and controlling linguistic choice to fulfil the rhetorical purpose tied to the genre*. Language is perceived to affect readers' response, and as such is a key strategic aspect in writing for science communication:

> "Opinion pieces are rhetorically tricky. To make it all come together… there's so little text to structure and change, they require a different rhetoric. I don't think it's problematic, just it requires a bit more thinking" (R2D3)

Writing an opinion piece for a national newspaper necessitates strategies focused on style and the readers' potential reactions:

> "If you write something for these [national] newspapers with a very wide readership, they are so tremendously different … To capture a reader, it can

> be important to imagine what the reader usually thinks about these topics. I try to not appear as very simplistic, one-track minded: then you can lose many potential readers" (R2D7)

> "If you write to a large public it might be a lot of people reading, so you have to take even more care about how you write things" (R2D1)

Monitoring and controlling linguistic choices are also central in academic writing, where word choices are carefully weighted to convey epistemic and attitudinal *stance*, i.e. the author's position in relation to the information presented (Hyland, 2005). As opposed to academic genres, however, word choice has clearly different rhetorical purposes in science communication: the aim is to achieve a direct, "punchy" style:

> "I go with linguistic intuition quite a bit … I try to have short sentences, be clear and not use any weak formulations, but rather be quite concrete and straight to the point … I don't think anyone who works in the evening newspapers [kvällstidningar] would think that it was a tabloid text, but compared with an academic text it has a little of that character." (R2D5)

Interestingly, since the language used in science communication was the participants' first language (Swedish), many of them described writing these genres as "liberatory" (R2D4) when compared to the use of English for publication, allowing more playfulness and control:

> "In Swedish, I can be more sort of playful and move things around more, precisely because I have a better feeling for it" (R2D5)

4.3 Self-reflection and evaluation

Regarding MSK in self-reflection, two strategies seemed predominant for evaluating writing outcomes: *trust their gut feeling/experience* and *ask feedback* from a colleague, editor, or someone from their social circles.

The first strategy meant ensuring that the original goal set for the task was met, whether it meant the clarity of the message, the interest of the topic, or just a sense that they accomplished what they wanted to convey. For example, R2D6 described how evaluating science communication writing is difficult (as opposed to research articles), trusting their gut feeling:

> "Ask yourself 'when do I think that it is good enough?' It's hard to say… it's a gut feeling in most cases. What matters is that it should be a current topic and the message should be clear." (R2D6)

R2D7 had similar reasoning:

> "You can always improve on a text … but I didn't feel like I needed to make alterations; I felt that it was good enough" (R2D7)

The concept of writing as continuous process, which is never done, was echoed by R2D4. Recognizing when it is time to move on is part of writing expertise:

> "It's not obvious when one is done, because there is always room for improvement, but I like to move on to new projects. … I can see that texts that I wrote lack something, but that's because I have evolved as a person since then, as a person and as a writer. It's not really something that a little more precision could have solved." (R2D4)

Secondly, another key strategy for evaluation is *asking feedback from others*, whether editors, co-authors, colleagues, or even family members. Feedback is important to ensure that a science communication piece is effective, convincing, and carefully worded:

> "I then let one of my colleagues read it" (R2D5)

> "I asked many people to read it and it became so much better, more carefully written… I got help even from my wife and my father-in-law. It went through so much scrutiny that it became very good" (R2D7)

Attention to language and wording once again is a strategy that could be assumed to be transferable from academic writing. In this respect, feedback from an external person becomes essential:

> "When I feel that I am almost done, I find a colleague to exchange ideas with, to make sure that it's clear … I always try to get a second opinion, to make sure that there are no questions or any loose ends." (R2D3)

The quality of the feedback is important for accurate evaluation because it leads to further revisions, what R2D2 called an *iterative process*, in which editors and co-authors have an important role. The quotes below underline aspects of *social-regulation* (Hadwin et al. 2018), where both co-authorship and collaboration with other writers led to evaluation and revision:

> "Editors are really important: they know what sells, so it's important to listen to them for the process to be iterative. Some people think: 'I'm a professor and you are just some editor: who are you to have opinions about my writing?' It's a good thing to learn from the start that [laughing] people will have opinions about your text and you shouldn't take that personally, because the text is much better for it." (R2D2)

> "I write this together with colleagues so it's the co-authors and the editor going through the text." (R2D1)

This process was not necessarily always smooth:

> "There was this process with an editor who had far-reaching opinions, quite frustrating." (R2D4)

Feedback is thus sought with the explicit purpose of self-reflection and revision, but note that it may result in frustration (R2D4) or defensiveness (R2D2), i.e. negative *self-reaction* (Zimmerman & Moylan, 2009). While these senior scientists seem to cope quite well with the setbacks and frustration attached to receiving critique (part and parcel of scientific publication, after all), novice academics may need scaffolding.

Related to self-reaction, it needs underscoring that *science communication efforts do not always elicit positive reactions by the public*. Some participants experienced reactions from readers and even political actors ranging from mixed or lukewarm responses to personal attacks and offensive commentary:

> "Mixed reactions on this article, but a lot of people appreciated how we managed to express ourselves in a calm and objective tone." (R2D4)

> "On a broader scale I do get some reactions, but not a lot… it's not like a huge amount of people get in touch with either positive or negative feedback" (R2D6)

R2D3's piece elicited a heated debate and even politicized reactions, which they seemed to take in their stride and even enjoy:

> "It received a lot of criticism, which was sort of fun. People reacted and that's what you want from an opinion piece, right [laughing] … There were people who didn't like it but also some nice comments. I thought it was nice that it led to a debate." (R2D3)

Other participants experienced angry comments on social media, calls and even personal attacks:

> "[someone] was being scornful on Twitter … people have been angry and phoned us." (R2D5)

For R2D7, the negative reaction was particularly hurtful, because criticism went beyond an informed scientific debate—which is expected and welcome in a democratic society—becoming *ad hominem* attacks:

> "It's been even worse for the article about [topic]. There were personal attacks on me, severe ones. I have challenged that dogma and that always means that you are questioned, quite rightly; you can expect opposition. But how it's done, how rude and unpleasant it can become. … There was backlash from trade associations; they suggested that I had somehow overinterpreted the results and fundamentally hinted that my research was

faulty, but many agreed that it made sense; the material from my study was not flawed." (R2D7)

These quotes illustrate dimensions of self-reaction that can be challenging for self-efficacy and motivation. Heated reactions, negative criticism and even just feedback tend to be more personal and public than what academics are used to receiving in research publication. The potential consequences, especially for novices, should not be underestimated.

5. Discussion

We aimed to examine senior scientists' MSK in the regulation of writing for science communication. Understanding their strategies, we argued, can provide an evidence base for training future academics, who are increasingly engaged in disseminating scientific knowledge outside the traditional academic publication channels (Luzón, & Pérez-Llantada, 2019; Pérez-Llantada, 2021b). To this end, we analyzed a selection of data obtained from in-depth narrative interviews with seven senior scientists with a robust record of science communication writing, and framed their MSK against the theoretical framework of self-regulation (Zimmerman & Moylan, 2009). These findings complement previous research on writing strategies in scientific writing (e.g. Berkenkotter & Huckin, 1993; Reid, 2019) and self-regulatory writing processes on a general level (e.g. Zimmerman and Risemberg, 1997) by focusing on science communication rather than scientific writing, and on process and concrete strategies rather than synthesizing a new theory (as Berkenkotter & Huckin, 1993), analyzing multimodal composing strategies (as Reid, 1997), or summarizing broader self-regulatory strategies such as self-monitoring and goal-setting (as Zimmerman and Risemberg, 1997). Our findings are summarized in Table 3.

First, Forethought strategies (Table 3) support theories posing that effective writing regulation is grounded on how the writing task is conceptualized (c.f. Harris et al., 2010): expert writers metacognitively choose their strategies based on their knowledge of the task conditions and reader expectations. All our participants metacognitively engaged in this crucial first step—task analysis—before writing, carefully considering how to adapt their strategies to the contextual demands. This finding recalls Wenden (1991), point about the cruciality of task knowledge for the successful regulation of rhetorical dimensions of writing, such as appropriateness of the message, and the adequacy and accurateness of linguistic choices.

Table 3. MSK in science communication writing according to SR phases

SR Phase	Strategies (themes) from out data
Forethought	Task analysis (conceptualization)
	Think about the argument and the story you wish to tell
	Consider the purpose of the text
	Consider the differences between science communication and scientific articles
	Think about the audience and how to translate complex scientific phenomena for this audience
	Planning and goal setting
	Goal setting: Convey scientific knowledge and a clear message
	Goal setting: Set content-related and rhetorically related goals
	Planning: Decide on the message (discussion w co-authors)
	Planning: Create a structure related to the goal
Performance control	Monitoring: Consider the relationship with academic genres and adapt strategies
	Monitoring: "The reader's mind": think of the readers' expectations and reactions to how the text is written
	Monitoring/control: Considering audience, carefully calibrate your linguistic and stylistic choices
Evaluation and Self-reflection	Evaluation/self-reflection: Trust gut feeling and/or experience about whether the initial goal is accomplished
	Evaluation: Seek feedback from others
	Self-reaction: Potential negative reactions to feedback, and potential negative reaction from audience response

It must be noted that our participants described writing processes for often very dissimilar genres (ranging from reports to the industry, non-fiction books, to opinion pieces in newspapers): as senior, established academics with considerable experience, they possessed the type of knowledge necessary to conceptualize these writing task accurately in terms of purpose, reader expectations, and form. For novice academics, accurate task conceptualizations may be more challenging. Additionally, in comparison to traditional academic genres (such as scientific articles), new genres of science communication tend to target less defined and specialized audiences (Luzón, & Pérez-Llantada, 2019), thus the purpose of the genre and the author's personal goal may be more significant for task analysis. Considering the great variety of genres in science communication and its multilingual dimension (Pérez-Llantada, 2021a,b), accurate task analysis should be the focus in science communication training: diversity of genres requires a diversity of strategies. Mentoring and co-authoring with experts (Florence & Yore, 2004)—as stressed by R2D5—and genre-based pedagogies (Swales, 1990), can effectively scaffold this key phase.

Secondly, participants developed strategies for planning, monitoring and evaluation based on both their knowledge of the task and their individual preferences—strategies that emerged from experience rather than training. These strategies encompassed self-questioning about the key message, the construction of an argumentative story, structuring the text with specific rhetorical patterns, and calibrating language and style. Additionally, they described specific strategies for co-authoring that involve some form of social regulation: writing for science communication may necessitate processes of co- and socially-shared regulation to be effective (Hadwin et al., 2018). Specifically, storytelling and message formulation emerged as central (see Table 3, Task Analysis and Performance Control). Participants envisioned their story and key message and planned the text accordingly. In monitoring and evaluation, strategies centered on imagining how the readers may react to the message, including the argumentative and linguistic choices used to convey it. While neither storytelling nor the consideration of the reader's mind are alien to academic writing (Tardy, 2005; Negretti, 2021), it should be noted that the concepts of "story" and "narrative" here seem to refer primarily to argument, i.e. aspects of rhetorical argumentation that allow the reader to participate in the reasoning behind the message being communicated and the argumentative evidence provided to support it including, but not exclusively limited to, its scientific basis. In this sense, as pointed out by Fahnestock (2020), the focus on narrative as a useful approach to science communication training (Baram-Tsabari & Lewenstein 2017; Dahlström, 2014; Jonsson & Grafström, 2020) needs to acknowledge that "narratives do not replace arguments but are tools of arguments in rhetoric" (p. 380).

Finally, the study consolidates the depiction of writing expertise as rhetorical flexibility, and the role of metacognition in the transfer of writing knowledge across genres. As conceptualized by Tardy and colleagues (2020), skilled writers are metacognitive about their writing knowledge, recontextualizing it across situations and readers. Our participants metacognitively linked and adapted their writing knowledge to and from academic and science communication genres (see Table 3, Task Analysis and Performance Control). Specifically, a strategy they transferred from academic to non-academic writing is the *careful monitoring and evaluation of linguistic choices with the purpose and reader in mind*, which in scientific publication enhances clarity and conveys epistemic stance (Hyland, 2005). This evidence supports research posing that effective pedagogies should encourage genre and language play to build linguistic and rhetorical awareness (Tardy, 2021), challenging the writer to reflect on how and why they adapt their writing strategies for different purposes and readers (cf. Cheng, 2007; Devitt, 2015; Negretti, 2021). This position is echoed in rhetorical critiques of current science communication practices: as Fahnestock (2020, p. 378, italics in original) puts it, "A rhetorician would be inclined to talk of *scientific argumentation* rather than *scientific information*, and of *weaker to stronger arguments*, including demonstrative proofs, rather than of *information* and *misinformation*."

Homing in on pedagogical implications, we can identify several points of contact with review studies examining what works in science communication training. Mercer-Mapstone and Kuchel (2017) listed twelve skills, among which we find several that evoke our findings: analyze the audience, calibrate the appropriacy of language and style for the genre's purpose and readers, use storytelling, and consider the mode and context. Many of these skills entail metacognitive strategies—planning, monitoring and evaluating one's work. On this point, it is worth noting the value of scaffolding MSK in science communication, since transfer may not always be straightforward. For example, while the strategy of explicitly researching the audience to anticipate readers' potential response is also important for scientific publication, it may require additional considerations when applied to science communication genres. Especially when science communication aims to manifests a democratic, critical perspective where the scientist is a citizen (Perrault, 2013), it requires that the writer takes a stance towards its audience that acknowledges its "rational capabilities" (Mellor, 2018, p. 750), to build an argumentative ethos. Nevertheless, science communication may result in reactions that are different from those one receives from academic colleagues, and our participants indeed reported receiving sometimes heated and negative, personal attacks. While there is no simple solution to this challenge, a first step is to raise metacognitive awareness of rhetorical orientations towards reader engagement, as well as how a text establishes relationships with readers (Perrault, 2013): "Depending on how texts pose problems, they may invite readers to be passive recipients of knowledge, or to be engaged coparticipants in figuring out what the knowledge means" (p. 113). In science communication training, a focus on MSK and the strategies summarized here can help novice writers conceptualize their mental models of science communication *and* how these models translate into arguments and into words.

We acknowledge that our findings are limited by the number of participants and by the fact that they are all established academics with seniority in their fields. Further research could thus compare strategies used by novice vs. experienced academics, possibly in writing the same genres. As illustrated in our data about self-reaction, early-career researchers may find writing for science communication particularly challenging (Mason & Merga, 2021), and targeted scaffolding on specific challenges may be most beneficial. Secondly, we recommend further inquiry on metacognition and the transfer of writing knowledge across genres, modes, and languages. While MSK provides an insight into verbalizable expert knowledge, it is possible that some aspects of our participant's expertise fall under "tacit knowledge" (Eraut, 2000), as suggested by their reliance on "gut feeling" for evaluation. This dimension needs to be taken into account in future investigation of transfer of knowledge across different genres, since the adaptation of strategies tied to style, language and rhetoric may not be straightforward (Driscoll et al., 2019; Kang, 2022; Tardy et al, 2020).

6. Conclusion

Science communication is crucial for a democratic society where academics take the role of "public intellectuals" (Said, 1995): experts with valuable knowledge that can participate in policy decisions, industrial collaboration, and the public debate. However, as one of our participants noted, "more is not necessarily better". Our study contributes a small but pivotal piece to fostering effective science communication by illuminating some of the self-regulatory and metacognitive mechanisms that underly its writing. In terms of science communication training, we suggest a greater focus on writing and argumentation, starting from genre analysis tasks and reflective practice with language and rhetoric, a focus "which is almost completely absent from the science of science communication literature" (Fahnestock, 2020, p. 383).

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Appendix A- Interview protocol

Part 1 – Your Experience

1. Could you tell us what the concept of "Science Communication" means to you?
2. Can you tell us what has been your experience with this over the years?
3. (Artifacts) Can you describe the story of these (1-3) examples that you brought to the interview?
    - What motivated you to write them?
    - Are they connected to scientific articles or other published work?
    - Tell us about any feedback or reaction you received

With regard to these examples that you brought today, we have a few more concrete questions about the writing process, perhaps comparing your experiences across your examples:

4. How familiar are you with these genres/type of text? Comparing scientific publication and public communication genres like these, what are the differences and similarities that you see across these types/genres?
5. How did you prepare before writing these texts? For example, did you plan the text beforehand?
6. Could you tell us concretely how you started the process of writing? What was the first thing you thought about?
7. As you were writing the text, can you describe the process of writing these texts? Did you have any specific strategy in mind, for instance? (style or language, or organization, argumentation and reader expectations). What did you pay most attention to?
8. How did you know that you were done? How did you evaluate your final outcome? What was important for you? Any editorial process involved?
9. How does language (Swedish or English) play a role in your writing this type of texts? Do you write these kinds of publications in more than one language? Do you have a preference? Does the language to be used affect what you produce in any way (in the writing process, ease of expression…)? How? Does language affect whether you write certain publications or not?
10. How has writing these texts given you an insight into yourself as a writer?

Part 2 – The bigger picture

A few questions about the overall role and space that science communication takes in your academic career.

11. In your view, how does your scientific work influence society? (its value and potential impact)
12. What is the value for you in writing these kinds of texts?

13. What is the space that this kind of work takes in your current work life and in your career overall?
14. Have you ever got anything back from this writing this type of science communication? For example, concrete collaborations but also ideas, inspiration, etc.? Have you experienced negative consequences in connection to your science communication efforts? Downsides?

<u>Part 3 – Your social context and story</u>

We are now interested to hear a bit more about the social aspects behind this kind of writing:

15. (Speaking of your immediate social context) How would you describe the overall perspective on science communication at your department and/or division?
16. (Re funding requirements) Do you choose what to write and who to write for?
17. Could you tell us about the kinds of experiences that helped you develop communication skills that are useful for this kind of writing? E.g. previous education, mentors, supervisors, etc.
18. How do you share your knowledge about science communication writing to others, for example your colleagues, students, or doctoral students?
19. Could you tell us about any co-authoring experiences of science communication? (if any)
20. How do you get help or support with science communication? (if you do)
21. Do you ever use the services of a professional communicator? (either the central communication office at Chalmers, your dept. communicator, or professionals outside the university)
22. Do you normally have a colleague or someone read these kinds of texts and give you feedback before you send it out? Or someone else who may represent your audience? Could you describe your experiences with feedback on this kind of writing? Do you have access to someone who can help you with texts other than scientific articles? (inside or outside academia)
23. Have you ever attended a writing workshop or course/similar focusing on this type of writing, i.e. science communication and writing beyond scientific publishing? Can you tell us about it?
24. Who should take responsibility/the lead for this kind of training?
25. In your view, how should Scientific communication skills be fostered among scientists? Who should take responsibility/the lead for this kind of training?

<u>Conclusion</u>

26. Is there anything else that you would like to share or experiences you would like to tell us about? (not writing)
27. What was missing from the interview that could have given you the opportunity to express your point of view?