This is a post-review, pre-print, accepted version of the article:

Lodén, A., Lönngren, J., & Ottander, C. (2024). Students' Reasoning on Searching Scientific Information Online: Developing a Model for Digital Versatility. *Nordic Studies in Science Education.*

Author names

Anna Lodén

Johanna Lönngren

Christina Ottander

Institution

Umeå University, Department of Science and Mathematics Education

E-mail addresses

anna.loden@umu.se (corresponding author)

johanna.lonngren@umu.se

christina.ottander@umu.se

Students' Reasoning on Searching Scientific Information Online: Developing a Model for Digital Versatility

Abstract

Accelerating digitalization actualizes the importance of secondary science education in developing students' digital abilities, such as retrieving and appraising scientific information online. However, there is little research and policy guidance on the purposes and challenges of teaching digital abilities in science classrooms. This article reports on a mixed-methods study that explored how upper secondary school students in Sweden reasoned about their digital abilities when searching for scientific information online. The results reveal three key themes: the role of scientific terminology in improving search accuracy, as students noted how precise terms yielded more credible results; the need for deliberate search strategies, including using questions or keywords depending on the context; and, the impact of selective exposure, as students became aware of how personalized results could reinforce existing beliefs and limit perspective diversity. Based on these insights, we introduce the concept of 'digital versatility' and outline a model, Digital Versatility in Online Searching (DVOS), that integrates essential digital abilities (source literacy, information abilities, and search abilities) with scientific subject knowledge. The DVOS model provides guidance for teachers in instructional planning and offers a basis for future research on digital abilities in science education.

Introduction

In a world where online environments are evolving at an accelerating pace, the challenge for the educational sector to keep up with this development is increasingly evident (Säljö, 2012, 2018; McGrew, 2020). Today's youth spend a significant amount of time online, making it crucial for education to assist students in developing the digital abilities necessary to navigate these complex environments (Caena & Redecker, 2019). This evolving digital landscape not only provides new opportunities for learning but also necessities a shift in educational approaches. The internet creates new opportunities for learning as it makes it possible to involve individuals from outside of the immediate student-teacher dynamic, increasingly opening classrooms to the outside world. In this context, the teacher's role becomes to facilitate interaction between students and online contributors or experts – rather than to transmit knowledge to students (Taekke & Paulsen, 2017). While such exposure to new perspectives can support learning, it also poses new challenges, including increased exposure to disinformation. This further emphasises the need for education to develop students' digital abilities such as digital literacy and communication (Ribble, 2011, 2021); the two abilities that are in focus in this study. This need is increasingly important in a post-digital era characterized by blurred boundaries between the physical and digital realms, as well as between human and non-human entities (Örtegren, 2022).

Previous research has identified three relevant aspects for developing students' digital ability to navigate complex online environments: (1) critically examining retrieved information (Carlsson & Sundin, 2018; Haider & Sundin, 2022; Nygren, 2019), (2) understanding the risks associated with selective exposure (Fasching & Schubatzky, 2022; Geschke et al., 2019; Otrel-Cass & Fasching, 2021), and (3) conducting searches for information online (Haider & Sundin, 2019, 2022). Education research has begun to address the first and second of these abilities in social science subjects (e.g., Carlsson & Sundin, 2018), but little is known about students' digital abilities related to searching for information online, in general, and in natural science subjects in particular. One example in science education is an empirical study in upper secondary education biology indicating that student achievement is contingent upon their abilities in evaluating online sources within the subject matter (Wiblom, Rundgren, & Andrée, 2017), which stresses the importance of further research in this area. This lack of research on students' ability to search for information online is problematic because teaching information retrieval is far from trivial. An excessive reliance on search engines for retrieving facts can even have negative consequences for learning, as easy access to information online can decrease our ability to remember such information (Kang, 2022). Individuals are less likely to remember the content of search results they obtained than the methods they used to access that information. For example, one may remember a search term used in a search, but not the information retrieved through that search term (Kang, 2022.). This challenge in retaining information is particularly relevant in the context of science education, where not only the retrieval but also the comprehension and retention of complex information are vital. Our study integrates the linguistic challenges with online searches in the realm of science education.

This study aims to develop insights about upper secondary school students' digital abilities and their strategies for searching for scientific information online. These insights can facilitate developing effective strategies to strengthen students' digital abilities in science education. The research questions in focus are:

1. How do upper secondary school students reason about digital abilities related to searching for scientific information online?
2. How do these students reason about the role of science knowledge when searching for scientific information online?

Background

Digitalization creates a need for expanded digital abilities

With the accelerating pace of digitalization, there is an increasing pressure for individuals to develop a comprehensive set of digital abilities, each highlighting different aspects and used in various contexts. In this text, we use the term 'abilities' for clarity and precision, as 'competence' can have multiple meanings depending on the context. Following Klieme's, Hartig's, and Rauch's (2008) definition of competence we here define *abilities* as context-specific cognitive dispositions acquired through learning. There are also many different definitions of digital abilities, and we have chosen to provide some examples to illustrate this diversity. For example, **digital competence** has been described as an individual's ability to understand and use digital tools and media, engage in coding, edit digital content, and participate in online fora (Pangrazio & Sefton Green, 2021; Punie, Brečko, & Ferrari, 2014; Voogt, 2012). A related concept is **digital literacy**, which encompasses the ability to understand, critically interpret, and utilize specific digital tools and media (Buckingham, 2015; Godhe, 2019; Pangrazio & Sefton Green, 2021). This concept extends to abilities such as locating, evaluating, and citing digital materials (Ribble, 2021). Another emerging concept is **media and information literacy**, which involves the ability to understand, interpret, and manage specific digital tools and media platforms (Haider & Sundin, 2018; Pangrazio & Sefton Green, 2021). Communication within a digital landscape varies depending on the type of device used. The concept **digital communication** is used to describe the nature of communication in terms of where and how one communicates within a digital landscape (Ribble, 2021). Ribble (2011) highlights the role of education to develop **digital citizenship** and has introduced a model that includes nine domains: access, etiquette, commerce, rights and responsibilities, literacy, law, communication, health and wellbeing, and security. This model is useful for exploring the relationship between individuals and the digital sphere, especially how individuals act and interact online (Pangrazio & Sefton Green, 2021).

Digital abilities in science education

Recent research points to a growing need to integrate teaching for digital abilities in natural science education, for example, when students use digital tools to explore the nature of science (Höttekke & Allchin, 2020). However, most existing studies have focused on digital abilities within the social sciences or treated it as a general skill. Similarly, many social science curricula prescribe that teachers should engage in developing students' abilities to search, structure, and evaluate information from the internet, while natural science curricula tend to approach digital abilities in a more superficial manner. For example, the Swedish upper secondary school curricula for the natural sciences subjects (The Swedish National Agency for Education, 2011, 2022) prescribe developing students' ability to use computer-aided equipment to collect data from laboratory experiments and simulations, but they do not mention abilities for searching for and critically reviewing information online. Similar trends are found in science curricula in Denmark (Undervisningsministeriet, 2020), Finland (Utbildningsstyrelsen, 2019), and the United Kingdom (The Department of Education, 2014). Norwegian curricula differ by offering a more comprehensive framework for digital competence that is applicable across all subject areas, including the natural sciences, and that addresses the ability to master search strategies, critically evaluate sources, and select relevant information about subjects to prepare students for citizenship in the digital society of the 21st century (Søby, 2018). However, criticism is directed also towards Norwegian curricula documents for lacking concrete guidelines on how these abilities should be taught (Lund, 2021). Therefore, we shift our focus to more specific areas that previous research has identified as crucial for developing digital abilities in science education. Two important areas are digital literacy (Nygren & Guath, 2022; Ribble, 2011) and digital communication of information (Nygren, Brounéus & Svensson, 2019; Nygren & Guath, 2022; Ribble, 2021).

Digital literacy

Research has shown that digital source criticism is particularly important for evaluating the correctness of complex information, such as scientific content (Nygren & Guath, 2022; Wiblom, Rundgren, & Andrée, 2017). Digital **source criticism** is often conceptualized as an element of digital literacy (Buckingham, 2015; From, 2017; Haider & Sundin, 2019; Henderson et al., 2015; Nygren et al., 2019; Nygren, Wiksten-Folkeryd, Liberg, & Guath, 2020; Ribble, 2021), encompassing not only the mechanics of search engines and the **trustworthiness of sources** but also evaluating individual **source credibility** and author biases (Sundin, 2024). Digital source criticism, in turn, consists of two parts: source evaluation and content assessment. The latter involves scrutinising whether the presented content is accurate and based on facts. This distinction between source evaluation and content assessment is crucial for navigating digital information with a critical and analytical approach (Sundin, 2024). However, studies of upper secondary school students' critical thinking and searching for scientific facts online have shown that students often do not engage in digital source criticism and instead rely on gut feelings (Wiblom, Rundgren, & Andrée, 2017). This highlights the need for teaching to build students' confidence in selected digital sources – a central aspect of **source trust** (Carlsson & Sundin, 2018). It is crucial to guide students towards a nuanced understanding of the trustworthiness of diverse sources to ensure they do not descend into a scepticism so profound that it precludes trust in any source and feeds conspiracy theories. Without source trust, students may find themselves further adrift in the sea of digital information (Sundin, 2022).

Understanding the relevance of subject competence for students' reasoning about source criticism in science is crucial. Subject competence includes knowledge and understanding of science concepts and adequate use of scientific language and is therefore an essential part of science education (Konicek-Moran & Keeley, 2015; Lemke, 1998). Scientific language differs markedly from everyday language as it is characterized by a high density of facts and a high level of abstraction. Scientists often use lengthy, subject-specific terminology and complex nominal phrases, creating a technical, abstract, and formal language, which presents significant challenges for science students (Fang, 2004; Ribeck, 2015). Research has shown that students must master scientific language to effectively process knowledge, develop arguments, and address scientific misconceptions (Henderson et al., 2015; Konicek-Moran & Kelley, 2015; Lemke, 1998; Nygren & Guath, 2022). Studies also indicate that early language competence is foundational for developing science literacy, as it supports the ability to comprehend and engage with scientific texts (Snow, 2016). Furthermore, vocabulary development, including the use of technical terms, is critical for students to transition from basic to advanced literacy in science education (Roessingh et al., 2016). In particular, the development of Tier 2 (general academic) and Tier 3 (subject-specific) vocabulary is essential for students to effectively understand and communicate complex scientific concepts, facilitating deeper engagement with science content (Ólafsdóttir et al., 2020). To further explore this, we draw on a distinction in linguistic research between practical skills—such as phonology, grammar, and vocabulary—and the abilities needed for tasks like conducting scientific experiments (Cavallo, 1996). The other type focuses on understanding, articulating, and explaining scientific concepts in an accessible way (Cavallo, 1996). Both abilities are essential for handling linguistic challenges in science education (Ribeck, 2015) and are likely also crucial for effectively searching for scientific information online.

Digital communication of information

Previous research has focused on upper secondary students' digital communication, highlighting the importance of understanding the process of generating, disseminating, and consuming scientific knowledge in the digital landscape (Nygren et al., 2019; Nygren & Guate, 2022). Although Nygren and co-authors research focused on social science education, we expect that digital communication is equally important in science education. Digital communication requires the abilities to discern what, where, and how to communicate in digital landscapes characterized by selective exposure, filter bubbles, and echo chambers (Ribble, 2021). Furthermore, Höttekke and Allchin (2020) have begun to explore the role of science education in raising students' awareness of selective exposure online, particularly in terms of exposure to pseudoscientific knowledge. Selective exposure occurs when search results are tailored based on previous searches and personal data stored on devices or accounts, often leading to individuals encountering information that aligns with their existing values and worldviews (Flaxman, 2016; Sunstein, 2009). This effect is often described through the concepts of filter bubbles (Pariser, 2011) and echo chambers (Geschke et al., 2019), where individuals are exposed repeatedly to similar perspectives and increasingly isolated from opposing views. Among these concepts, the notion of filter bubbles plays a significant role in explaining selective exposure. For example, the triple-filter-bubble model (Geschke et al., 2019) explains this phenomenon across three levels: personal, social, and technical. At the personal level, individuals engage with information that confirms their existing attitudes and self-perceptions, avoiding cognitive dissonance (Festinger, 1957; Swann, 1989). Socially, online friendships often form among people with similar sociodemographic and personal characteristics, leading to reduced exposure to differing opinions (McPherson, Smith-Lovin, & Cook, 2001; Nicholas, 2015). Technically, search engines filter information to cater to the assumed needs of users, resulting in personalized search results and potentially narrower perspectives (Geschke, Lorenz & Holtz, 2019; Nguyen, 2020; Pariser, 2011). Understanding how filter bubbles develop and recognizing one's susceptibility to filtered information is crucial in addressing the challenges of selective exposure (Geschke et al., 2019). However, in a study by Otrel-Cass and Fasching (2021) conducted in Denmark and Austria, students (14-24 years old) showed limited knowledge about how algorithms, filter bubbles, and echo chambers impact online information exposure. Some students trusted information aligning with their beliefs, while others recognized the need to learn more about these phenomena. Similarly, in Sweden, Haider and Sundin (2016) have advocated for educational curricula to cover abilities in searching, communicating, and generating information online, as well as critical awareness of how algorithms shape digital spaces. Given this emphasis on search abilities, it is essential to understand the different types of online search activities students engage in. Marchionini (2006) has described three main types of online search activities that focus on the outcome of the search: 'Lookup', which includes basic searches for specific answers or facts; 'Learn', which involves iterative searches and cognitive processing and can lead to learning and understanding; and 'Investigate', which requires in-depth analysis and synthesis of search results over extended periods. Since previous research has shown that students may engage in lookup search activities – at the expense of learning and understanding (Haider & Sundin, 2019; Rieh, Thompson-Collins, Hansen, & Lee, 2016) – this distinction between different search activities is highly relevant for this study.

Methods

To guide our data collection and analysis, we used two abilities identified as especially important in education by Ribble (2011): **digital literacy** and **digital communication**. To explore those abilities, we conducted a mixed-methods study with secondary students in the context of science education.

Study Participants

Our data was collected from four upper secondary science classrooms during lectures in biology and science studies. We included three groups from higher education preparatory programs and one from a vocational program (Table 1). The 68 participants (17-19 years old) included 44 female students, 22 male students, and two students who did not want to specify their gender. The study was conducted during the COVID-19 pandemic, which meant that we conducted parts of the data collection online.

Data collection

Our mixed-methods approach included three types of data collection (Table 1). Firstly, we asked students to complete a web questionnaire (Appendix 1). Secondly, we collaborated with science teachers to develop an in-class exercise that was aligned with the official syllabi for all four classes and focused on digital literacy and digital communication (Ribble, 2011). During the exercise, we showed the students screenshots of the results from four Google searches that had been conducted on four different computers, two of which used ‘anti-vax’ as a search term and two that used ‘anti-vaxx’. Then, we asked the students to analyse the screenshots and answer the following questions in writing: *Can you identify any differences or similarities between these screenshots?*, *What do you think those might be due to?*, *What do you think of the different keywords that were used and the results the four searches produced?* The written responses and the questionnaire data were collected anonymously using shared OneDrive folders. Thirdly, we conducted audio-recorded focus group interviews to obtain in-depth qualitative data on students’ reasoning about their experience of searching for information online. We chose a group format to allow participants to collectively explore, clarify, and compare their experiences and understandings of digital abilities (Robson & McCartan, 2019). 13 students participated, divided into six focus groups with two to three students each. In one of the participating classes (1a), students were selected randomly, utilizing the online digital tool *Spin the Wheel*. In the other three classes, we used a convenience sample, including all students who volunteered to participate. The discussions were led by the first author and lasted 50–70 minutes. Our discussion guide included questions focusing on digital abilities in general and on how students’ reason about different aspects of digital abilities. We also posed follow-up questions to encourage deeper reflection and dialogue among participants, such as *What do you mean by that?* or *Can you tell us more about that?*.

We adhered to the relevant regulations (GDPR) and the ethical principles outlined by the Swedish Research Council (2017) regarding informed consent, right to withdraw from participation, confidentiality, and handling of personal data. The mixed-methods approach allowed us to collect complementary data and helped us develop a multifaceted understanding of the subject. More specifically, the quantitative data provided an initial overview of students' perspectives, even though the amount of data was not sufficient for reaching statistical significance. The qualitative data offered deeper insights and understanding of the students' perspectives and reasoning. In the classroom exercises and focus group discussions, the first author's extensive experience working with upper secondary students allowed them to create an open and safe dialogue and to elicit genuine and honest responses.

Table 1: Overview of participants and data collection instances. Data collection types are Q = questionnaire, E = exercise, F = Focus group

School	Program type	Subject	Participants	*n* participants in each data collection instance
1a	higher education preparatory	Science studies	21 (of 32) students Even distribution between the gender	Q: 21 E: 21 F: 4 (2 pairs)
1b	higher education preparatory	Science studies	29 (of 32) students Predominantly females (2/3)	Q: 29 E: 29 F: 4 (2 pairs)
1c	vocational	Science studies	4* (of 7) students Females only	Q: 4 (online) E: 4 (online) F: 3 (online)
2	higher education preparatory	Biology	14 (of 20) students Even distribution between the gender	Q: 14 E: 14 F: 2 (online)

* This class at the vocational program class was exceptionally small, comprising a total of seven students, of whom four took part in our study. The education is an apprenticeship program that normally has few students.

Data analysis

We structured our analytical framework based on Ribble's (2011, 2021) descriptions of digital literacy and digital communication. Ribble's concept of digital literacy, which concerns students' ability to critically and responsibly navigate digital information, provided a basis for analyzing students' reasoning about search strategies and the credibility of information sources. The concept of digital communication, focused on skills related to online information exchange, helped us analyze how students engaged with scientific content and communicated in digital settings. Together, these aspects enabled us to address both the technical and cognitive dimensions of students' digital abilities.

In our study, we employed abductive and reflexive thematic analysis (Braun, Clarke, & Hayfield, 2019; Kvale, 2014), for example by reflecting over possible bias due to the long experience of being a teacher, and the results from the questionnaire. As Braun and Clarke (2022) emphasize, thematic analysis should be seen as a constructive and dynamic method where the researcher plays an active role in generating meaningful themes, rather than simply allowing themes to 'emerge' naturally from the data. The analysis was conducted in two phases to ensure a systematic and transparent process, while we also engaged in reflexive practice. This involved carefully considering our methodological choices and approach to the data throughout the analysis. The excerpts were analysed in Swedish, but all excerpts reproduced in this paper were translated to English by the authors, supported by ChatGPT 4.

Phase 1: Deductive Analysis. In the first phase, Ribble's framework of digital literacy and digital communication guided our analysis and helped identify initial themes. With Ribble's focus on responsible digital communication, we examined how students used digital language and strategies, leading to themes such as search terms, search strategies, and selective exposure. These themes emerged naturally from the data and were organized as main themes to reflect students' digital skills and awareness of their digital footprint. For example, the theme of search terms captured how students used formal language and scientific terminology in their digital searches, aligning with Ribble's emphasis on purposeful communication in online contexts.

Phase 2: Inductive Analysis. The second phase involved an inductive analysis to further develop and refine the themes identified in Phase 1, including sub-themes and codes. For instance, the *theme* of search strategies was expanded with the *sub-theme* of search history, and one of the *codes*, cookies, captured students' reflections on how these influence the information they encounter online. This inductive phase provided insights that extended beyond Ribble's framework and offered a more comprehensive understanding of students' digital navigation and critical engagement with online content. Tables 2 and 3 summarize our analysis, showing how data from the questionnaires, reflections and discussions contributed to a transparent and traceable analytical process.

Table 2. Summary of themes, subthemes, and supporting codes.

Theme	Subtheme	Supporting codes
Search terms	Use of terms	Scientific concepts, spelling, multiple terms, formal language
Search strategies	Patterns in search history	Search engine, search result page (SERP), links, cookies, IP-addresses
Selective exposure	Navigating content	Personalized information, filter bubbles, Echo chambers

Table 3. Summary of the data types and quantities contributing to each of the three themes. **# = questionnaire number**

Theme	Analysed questionnaire items (*n* responses)	*n* excerpts from written reflections	*n* excerpts from focus group discussions
1 Search terms	#28, open-ended (68)	36	112
2 Search strategies	#25, 28, 32, open-ended, & 24, 26–27, 29–31, multiple-choice (68)	36	70
3 Selective exposure	#28, open-ended, & #27, 39, 40, multiple-choice (68)	6	42

Data saturation was reached for themes 1 and 2 in the analysis of data from the written reflections and focus group discussions, enhancing the reliability of these themes and the conclusions drawn from them. For theme 3, saturation was primarily achieved during the focus group discussions after more extensive deliberations, further emphasizing the complexity and significance of that theme.

Results

Our analysis resulted in three themes focusing on science concepts as search terms, search strategies in science learning, and selective exposure, respectively. These themes are partly overlapping and shed light on students’ reasoning about searching for information online in science classrooms.

THEME 1 – Accurate use of science concepts as search terms

The first theme concerns students' reasoning about their use of **search terms**, **spelling** of those terms, and experimenting with **multiple terms** to refine the outcomes. This theme arose from codes like scientific concepts, spelling, multiple terms, and formal language use of scientific terms (Table 2). Example quotes will follow.

In the focus group discussions, several students emphasized the importance of formal terms to obtain precise results. For example, one student noted that terms like 'anti-vaccine' or 'resistant to vaccine' yield better results than 'anti-vax' or 'anti-vaxx'. Another student commented: *I would not have written 'anti-vax' or 'vax' if I wanted to find a credible source, then I would have searched for something more serious, like 'anti vaccine' or 'resistant to vaccine.'* Students connected this to science education, suggesting formal language in school-related searches leads to more accurate search results, and that knowing synonyms for scientific concepts aids in finding science-based facts for assignments. They also indicate that understanding scientific concepts enhance search precision and efficiency, as specific terms help retrieve authoritative information: *Like, if you search for photosynthesis, you get more 'expert pages' that use those terms...* and *What's cellular respiration, you know, kinda like that. Once you get the basics of the subject, it makes searching way so much easier*. They suggested that using precise scientific language in queries, produce more trustworthy sources: *If you write it in a more professional way with the real word you will probably find more trustworthy sources than if you search with an abbreviation*. On spelling, students noted that misspelled search terms can lead to unreliable results. One student wrote that *it* [the search term] *can be misspelled, which can lead you to visit less reliable websites*. In the in-class exercises, 70% of the participants believed correct spelling is essential for accurate results, no one mentioned spelling's impact before the exercise. This shift may have resulted from exercises demonstrating different spellings (anti-vax, anti-vaxx), which underscored spelling's importance. Despite deeper reflections in focus group exercises, students admitted they had not previously considered search terms strategies. Some requested more explicit teaching on this, while others expressed confidence in their ability due to years of online searching experience.

THEME 2 – Deliberate search strategies in science learning

The theme explores students' reasoning about search strategies in science learning, including their approach to information retrieval, their understanding of search engines, and reflections strategy effectiveness. Derived from codes on search behaviors, including how students identify relevant information, access credibility, and synthesize it (Table 2). Topics concerns students' reasoning regarding search engines, search engine result page (SERP), links, cookies, and IP-addresses. Example quotes follow.

Most participants (78%) claimed an understanding of what search engines are (item 24), and 97% found them easy to use (item 26). This is supported by qualitative data from the in-class exercise, where students demonstrated their understanding of how to use search engines as well as their ability to identify relevant and credible information and synthesize into a coherent understanding of a topic. Students described various strategies for using questions or keywords based on context: *If I want to know something quickly, I use a whole question, so I get an answer right away.* Others mentioned keywords (i.e., single words or combining both approaches, *[first] typing a question, but if nothing good comes up typ[ing] a concept instead.* Many students emphasized conducting multiple searches but admitted that they rarely performed more than two to three searches for the same topic. They also generally avoided scrolling past the first page of result, with some avoiding top results as: *often not as credible*. This suggest that students rely on habits or intuition: *Yeah… you kinda know right away if you're gonna use it or not.* Students justified these habits saying that they are adept at navigating online and need no further strategies, often finding what they need within three attempts. However, they later reflected that such habits might limit exposure to diverse perspective, reinforcing biases. Students expressed interest in learning more effective strategies for science content. Suggesting science teachers encourage independent searches instead of providing links. They also proposed tailored training for digital abilities in different subjects, noting the different analytical and evaluative approaches required in the social versus natural science: *for instance, social science students might analyse and evaluate different aspects and perspectives than natural science students.* Despite students' confidence their limited strategic depth underscores the need for education to integrates critical thinking, sources criticism, and trust.

THEME 3 – selective exposure, a double-edged sword in online searches

The third theme explores students' reasoning about selective exposure in online searches where individuals, consciously or unconsciously, seek information that reinforces their existing beliefs. This theme examines the students' understanding of selective exposure influences on search results and awareness of personalized information. Although many initially showed low awareness of selective exposure, particularly in their questionnaire responses, the in-class exercises and focus group discussions revealed a more nuanced understanding as students engaged with real-world examples. This theme derives from codes on perceptions of search result variability, personalized information, filter bubbles, and echo chambers, and the impact of algorithms on information retrieval (Table 2). Example quotes follow.

In the focus group discussions, many students were uncertain about selective exposure, associating it mainly with personalized advertisement rather than searching for factual knowledge. In the questionnaire responses (item 27, multiple choice), 80% believed that two different computers would yield the same results, indicating low awareness of how search algorithms personalize results based on user behaviour. Only 25% thought past searches could influence subsequent searches (item 28, open-ended) and 10% explicitly suggested that search results would remain identical, regardless of the computer used (item 28, open-ended). However, in-class exercise demonstrated a different perspective; when shown varying search results from different computers, students realized that two identical searches can yield different outcomes. Some suggested that search engines adapt based on user's profiles, past searches, and/or personal opinions. One student observed that search results tend to be: *shaped by what one seems to be interested in, what they* [the company providing the search engine] *know one wants to see*. Students described selective exposure as a double-edged sword. On the one hand, some students argued that it can be convenient and timesaving to receive individually tailored information as search engines then provide useful: *recommendations based on our interests.* One student argued: *I think it is good that you get your searches* [search engines answer] *based on what you're looking for*. On the other hand, there were concerns that selective exposure can confirm incorrect beliefs and create informational bubbles: *you can easily get stuck in your own bubble when you're provided with information that supports it*. This suggests students may be receptive to learning more about selective exposure's functioning and impact.

Discussion

In this section, we focus on two key areas that previous research has identified as essential for developing digital abilities in science education: digital literacy (Nygren & Guath, 2022; Ribble, 2011) and digital communication of information (Nygren & Guath, 2022; Ribble, 2021). Based on our results, we suggest a more nuanced description of these abilities, and a comprehensive concept and model to describe their interplay.

Digital literacy

Digital literacy includes critical reasoning and trust in carefully selected online sources (Buckingham, 2015; Godhe, 2019; Haider & Sundin, 2019; Nygren et al., 2019; Pangrazio & Sefton Green, 2021). Our findings indicate that many students rarely perform more than two to three searches for the same topic and never explore beyond the first page. This limited search behavior can hinder their critical evaluation ability to identify trustworthy sources. Some students avoid the top search results viewing them as less credible without clear reasoning. Additionally, students' quick judgement about the usefulness of a web page underscores the need to foster more reflective and informed search strategies. After the in-class exercise, students in our study realized that using specific scientific terms and formal language can improve search accuracy, suggesting that subject knowledge enhances source criticism. We suggest that digital literacy in science education should include both subject knowledge and source literacy. Here literacy is defined as comprising source trust and source criticism. Subject competence encompasses knowledge and understanding of scientific concepts as well as the appropriate use of scientific language (Wiblom, Rundgren, & Andrée, 2017). It enables students to critically evaluate scientific information, and it has been described as essential for developing a deeper understanding of scientific processes and methods (Konicek-Moran & Keeley, 2015). In our study students expressed a desire to learn how to effectively integrate scientific concepts into their online searches. They highlighted, for example, that understanding scientific concepts enhances the efficiency and precision of their searches and that formal language in searches leads to more accurate results. They also recognized that subject-specific knowledge is crucial for critically appraising scientific facts online, which supports previous research indicating the need for both general and subject-specific knowledge to maintain a critical stance during online searches (Nygren, 2019). These findings align with previous studies indicating that early language competence is fundamental for developing science literacy, as it supports the ability to comprehend and engage with scientific texts (Snow, 2016). Furthermore, vocabulary development, including the use of technical terms, is critical for students to transition from basic to advanced literacy in science education (Roessingh et al., 2016). Our results highlight the challenges students face in developing this form of literacy, particularly in navigating and understanding online scientific information.

Digital communication

Like with digital literacy, our findings suggest that digital communication can be divided into two components: information competence and search competence. Information competence in the digital realm has been described as involving technical abilities (Punie et al., 2014; Säljö, 2012; Voogt, 2012) and the digital interaction (Pangrazio & Sefton Green, 2021; Ribble, 2011; Wiblom, Rundgren, & Andrée, 2017). In our study some students described selective exposure as a time-saving feature of search engines, aligning with studies indicating a preference for information that reinforces existing attitudes and avoids cognitive dissonance (Geschke, 2019; Sunstein, 2009). However, students also reasoned about potential drawbacks of receiving personalized results, suggesting that personalization might narrow worldviews echoing concerns about 'filter bubbles' and 'echo chambers,' (Nguyen, 2020). These reflections demonstrate the complexity students face when navigating online information (Geschke et al., 2019; Otrel-Cass & Fasching, 2021), which may lead to shallow information seeking, relying on algorithm-selected sources. In a democratic society, students must develop a critical understanding of, and approach to, searching for information online (Örtegren, 2022). In addition to information competence, our findings suggest that students also need search competence, which includes effective search behavior and use of search engines (cf. Haider & Sundin, 2016, 2019, 2022; Geschke et al., 2019; Otrel-Cass & Fasching, 2021; Wiblom, Rundgren, & Andrée, 2017). For instance, students in our study reported relying on intuition rather than deliberate search strategies, consistent with prior research (Wiblom, Rundgren, & Andrée, 2017). To address these issues, it is vital to develop students' understanding of scientific content and their practical abilities for online searching abilities. Science teachers can plan for activities where students can use 'comprehensive searches' (Marchionini, 2006), involving more in-depth, subject-specific queries, that require deliberate search strategies. Developing deliberate search strategies could help students balance source criticism and source trust (Wiblom, Rundgren, & Andrée, 2017), indicating a close link between search competence and source literacy.

Digital versatility in science education

Our results indicate a need for teaching that allows secondary school science students to use deliberate search strategies and to combine digital abilities with a solid understanding of scientific concepts. To improve the design and delivery of such teaching, we also see a need to further explore how both understanding and practical skills contribute to effective online searches for scientific information. To address these needs in science education practice and research, we introduce the concept of **digital versatility**, which encompasses the essential digital abilities and knowledge that equip students to navigate, search, and critically evaluate scientific information online. To concretize this concept, we have developed the **Digital Versatility in Online Searching** (DVOS) model (Figure 1), which includes four essential components: subject competence and three types of digital abilities: source literacy, information abilities, and search abilities.

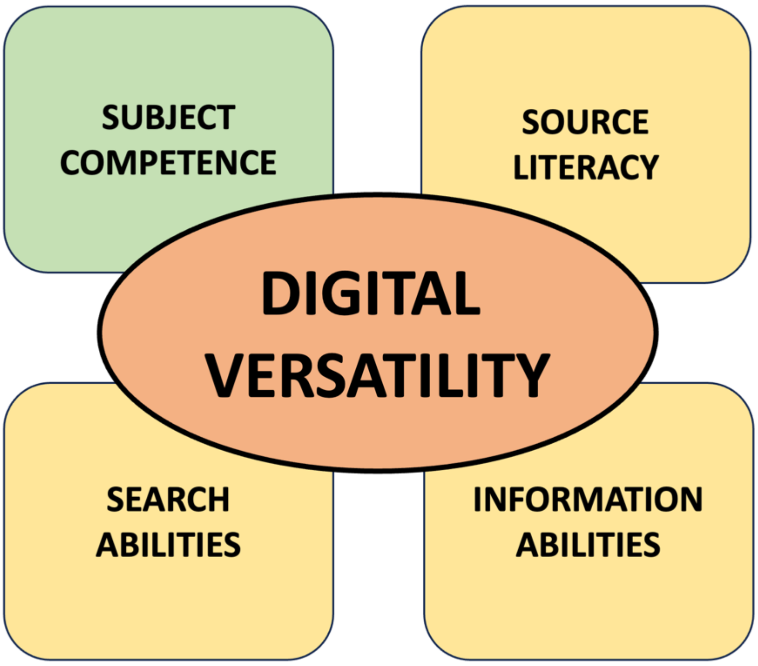

Figure 1. Model of digital versatility with four components. The green box represents subject competence, and the yellow boxes represent three digital abilities. The four components are not isolated from each other, and they are all essential for achieving digital versatility.

Each of these components is crucial for improving science students' critical engagement with digital content. The model provides a conceptual basis for comprehensive teaching and research on digital versatility, emphasizing the importance of combining these abilities in online searchers. For the four components of digital versatility, future research could identify specific knowledge that supports students' development of practical abilities and vice versa, exploring how these knowledge types develop together. For example, research could examine the effects of teaching science to integrate formal scientific language and concept-specific terminology into search strategies. Additional studies might also investigate how search abilities manifest in practice by analyzing students' real-time search behaviors while they work on scientific tasks. Finally, research can examine how teachers can address digital versatility to develop students' search abilities in science.

Conclusion

Motivated by rapid technological advancements and evolving requirements for digital abilities, we studied how upper secondary school students' reason about their digital abilities when searching for scientific information online. We identified three themes in students' reasoning, focusing on the need for students to accurately use science concepts as search terms, employ deliberate search strategies, and be aware of the diverse impacts of selective exposure. Our results also suggest that students may be overconfident in their use of search engines, highlighting a need for science education to focus more on both source literacy and comprehensive search strategies. The findings also point to the need for curriculum updates to reflect the digital abilities in today´s science education. To support this development in science teaching, curriculum documents updates, and further research, we developed the DVOS model. The model integrates subject competence, source literacy, information competence and search competence. While our study has focused on subject competence alongside digital abilities, we expect that all four components in the model benefit from a balanced integration of these abilities. We hope that the three themes and the DVOS model can serve as practical tools for science educators and to inspire and inform further research on digital abilities in science education.

References

Buckingham, D. (2015). Defining digital literacy – What do young people need to know about digital media? *Nordic Journal of Digital Literacy*, *10*, 21-35. https://doi.org/10.18261/ISSN1891-943X-2015-jubileumsnummer-03

Braun, V., Clarke V., & Hayfield, N. (2019). 'A starting point for your journey, not a map': Nikki Hayfield in conversation with Virginia Braun and Victoria Clarke about thematic analysis. *Qualitative Research in Psychology*, *19(*2), 424-445. https://doi:10.1080/14780887.2019.1670765

Caena, F. & Redecker, C. (2019). Aligning teacher competence frameworks to 21st century challenges: The case for the European Digital Competence Framework for Educators (Digcompedu). *European Journal of Education*, *54*, 356-369. https://doi.org/10.1111/ejed.12345

Carlsson, H. & Sundin, O. (2018). *Sök- och källkritik i grundskolan: En forskningsrapport*. Lund University.

Cavallo, A. M. L. (1996). Meaningful learning, reasoning ability, and students' understanding and problem solving of topics in genetics. *Journal of Research in Science Teaching. 33*(6), 625-656. https://doi.org/10.1002/(SICI)1098-2736(199608)33:6

Fang, Z. (2004). Scientific Literacy: A Systemic Functional Linguistics Perspective. *Science Education, 89*(2) 335-347. https://doi.org/10.1002/sce.20050

Fasching, M. & Schubatzky, T. (2022). Beyond truth: Teaching digital competences in secondary schools to counteract disinformation. Experts' views on practical teaching frameworks for basic digital education in Austria. *Medienimpulse*. *60*(3), 66. https://doi.org/10.21243/mi-03-22-19

Feinstein, N. (2010). Salvaging Science Literacy. *Science Education*. *95*(1), 168-185. https://doi.org/10.1002/sce.20414

Festinger, L. (1957). *A Theory of Cognitive Dissonance.* Stanford University Press.

Flaxman, S., Goel, S., & Rao, J. (2016). Filter bubbles, echo chambers, and online news consumption. *Public Opinion Quarterly*, *80,* 298-320. https://doi:10.1093/poq/nfw006

From, J. (2017). Pedagogical Digital Competence—Between Values, Knowledge and Skills. *Higher Education Studies*. *7*(2), 43-50. https://doi.org/10.5539/hes.v7n2p43

Geschke, D., Lorenz, J., & Holtz, P. (2019). The triple-filter bubble: Using agent-based modelling to test a meta-theoretical framework for the emergence of filter bubbles and echo chambers. *British Journal of Social Psychology*, *58*, 129-149. https://doi.org/10.1111/bjso.12286

Godhe, A-L. (2019). Digital Literacies or Digital Competence: Conceptualizations in Nordic Curricula. *Media and Communication*, *7*(2), 25-35. https://doi.org/10.17645/mac.v7i2.1888

Haider, J. & Sundin, O. (2016). *Algoritmer i samhället.* Kansliet för strategi- och samtidsfrågor, Regeringskansliet. Lund University.

Haider, J. & Sundin, O. (2018). *Medie- och informationskunnighet i den digitala tidsåldern, en demokratifråga: kartläggning, analyser, reflektioner*. U. Carlsson (Ed.) Nordicom UNESCO-professuren i yttrandefrihet, medieutveckling och global politik vid Göteborgs universitet.

Haider, J. & Sundin, O. (2019). *Invisible Search and Online Search Engines: The Ubiquity of Search in Everyday Life.* Routledge. https://doi.org/10.4324/9780429448546

Haider, J. & Sundin, O. (2022). *Paradoxes of media and information literacy: The Crises of Information. Routledge*. https://doi.org/10.4324/9781003163237

Henderson, J. B., MacPherson, A., Osborne, J., & Wild, A. (2015) Beyond Construction: Five arguments for the role and value of critique in learning science. *International Journal of Science Education*, *37*(10), 1668-1697. https://doi.org/10.1080/09500693.2015.1043598

Höttekke, D. & Allchin, D. (2020). Reconceptualizing nature-of-science education in the age of social media. *Science Education*, *104*, 641-666. https://doi.org/10.1002/sce.21575

Kang, E. (2022). Easily accessible but easily forgettable: How ease of access to information online affects cognitive miserliness. *Journal of Experimental Psychology. Applied*, 29. https://doi.org/10.1037/xap0000412

Klieme, E., Hartig, J., & Rauch, D. (2008). The Concept of Competence in Educational Contexts. In J. Hartig, E. Klieme, D. Leutner (Eds.). *Assessment of Competencies in Educational Contexts*, (s. 3-22). Ashland, OH: Hogrefe & Huber Publisher.

Konicek-Moran, R. & Keeley, P. (2015). *Teaching for Conceptual Understanding in Science.* Arlington: NSTA Press.

Kvale, S. & Brinkmann, S. (2014). *Den kvalitativa forskningsintervjun.* Lund: Studentlitteratur.

Lemke, J. L. (1998). Multiplying meaning: Visual and verbal semiotics in scientific text. In J.R. Martin & R. Veel (Eds.), *Reading Science. Critical and functional perspectives on discourses of science.* 87-114. Routledge.

Lund, A. (2021). The Norwegian Ministry of Education and Research's action plan for digitalization in primary and secondary education and training: appraisal and critique. *Nordic Journal of Digital Literacy*, *16*(1), 34–42. https://doi.org/10.18261/issn.1891-943x-2021-01-04

Marchionini, G. (2006). Exploratory search: From finding to understanding. *Communications of the ACM*, 49(4), 41-46. https://doi.org/10.1145/1121949.1121979

McGrew, S. (2020). Learning to evaluate: An intervention in civic online reasoning. *Computers & Education*. *145*. https://doi.org/10.1016/j.compedu.2019.103711

McPherson, M., Smith-Lovin, L., & Cook, J. (2001). Birds of a feather: Homophily in Social Networks. *Annual Review of Sociology*, *27*, 415-444. https://doi:10.3410/f.725356294.793504070

Nguyen, C. T. (2020). Echo chambers and epistemic bubbles. *Episteme*, *17*(2), 141-161. https://doi.org/10.1017/epi.2018.32

Nicholas, A. J. & Dvir-Gvirsman, S. (2015). "I Don't Like You Any More": Facebook Unfriending by Israelis During the Israel Gaza Conflict of 2014. *Journal of Communication*, *65*(6), 953-974. https://doi.org/10.1111/jcom.12188

Nygren, T. (2019). *Fakta, fejk, fiktion, källkritik, ämnesdidaktik, digital kompetens*. Stockholm: Natur & Kultur.

Nygren, T., Brounéus, F., & Svensson, G. (2019). Diversity and credibility in young people's news feeds: A foundation for teaching and learning citizenship in a digital era. *Journal of Science Education. 18*(2), 87-109.

Nygren, T., Wiksten-Folkeryd, J., Liberg, C., & Guath, M. (2020). Hur motiverar gymnasieelever sina bedömningar av trovärdiga och vilseledande digitala nyheter? *Journal of Humanities and Social Science Education*, Nordidactica 2020(2).

Nygren, T. & Guath, M. (2022). Students Evaluating and Corroborating Digital News. *Scandinavian Journal of Educational Research*, *66*(4), 549-565. https://doi.org/10.1080/00313831.2021.1897876

Ólafsdóttir, S., Laster, B., & Stefánsson, K. (2020). Adolescent learning of academic vocabulary in Iceland. *Journal of Adolescent & Adult Literacy*, *64*(1), 79-87. https://doi.org/10.1002/jaal.1055

Otrel-Cass, K. & Fasching, M. (2021). Postdigital Truths: Educational Reflections on Fake News and Digital Identities. Jandric, P. (Ed.) *Postdigital Humans: Transitions, Transformations and Transcendence.* 89-108. Savin-Baden: Springer. https://doi.org/10.1007/978-3-030-65592-1_6

Pangrazio, L. & Sefton-Green, J. (2021). Digital rights, digital citizenship and digital literacy: What's the difference? *Journal of New Approaches in Educational Research, 10* (1), 15-27. https://doi.org/10.7821/naer.2021.1.616

Pariser, E. (2011). *The Filter Bubble: What the Internet is Hiding from You*. New York: Penguin Press.

Punie, Y., Brečko, B., & Ferrari, A. (2014*). DIGCOMP: A Framework for Developing and Understanding Digital Competence in Europe*. http://www.openeducationeuropa.eu/nl/elearning_papers. *38*, 3-17

https://doi.org/10.2788/52966

Ribble, M. (2011). *Digital Citizenship in Schools, Second Edition (2nd.)*. Eugene, OR:ISTE

Ribble, M. (2021). Digital Citizenship in the Frame of Global Change. *International Journal of Studies in Education and Science*, 2(2), 74-86. https://doi.org/10.46328/ijses.30

Ribeck, J. (2015*). Steg för steg - Naturvetenskapligt ämnesspråk som räknas*. Språkbanken Department of Swedish University of Gothenburg.

Rieh, S. Y., Thompson-Collins, K., Hansen, P., & Lee, H-J. (2016). Towards searching as a learning process: A review of current perspectives and future directions. *Journal of Information Science*, *42*(1), 19-34. https://doi.org/10.1177/0165551515615841

Robson, C. & McCartan, K. (2019). *Real world Research* (4th edition). Glasgow: Bell & Bain Ltd.

Roessingh, H., Douglas, S., & Wojtalewicz, B. (2016). Lexical standards for expository writing at Grade 3: The transition from early literacy to academic literacy. *Language and Literacy*, *18*(3), 123-144.

Snow, P. C. (2016). Elizabeth Usher Memorial Lecture: Language is literacy is language-Positioning speech-language pathology in education policy, practice, paradigms and polemics. *International Journal of Speech-Language Pathology*, *18*(3), 216-228.

Säljö, R. (2012). Literacy, Digital Literacy and Epistemic Practices: The Co-Evolution of Hybrid Minds and External Memory Systems. *Nordic Journal of Digital Literacy*, 1, 5-19. https://doi.org/10.18261/ISSN1891-943X-2012-01-02

Säljö, R. (2018). Symboliska teknologier och lärande i en digital tid – om samspelet mellan samhälle, teknik och kognitiva vanor. *Pedagogisk forskning i Sverige, 23*(5), 168-183. https://doi:10.15626/pfs23.5.10

Søby, M. (2018). *Norway, Country Report on ICT in Education*. European Schoolnet.

Schwarts, D. L., Tsang, J., & Blair, K. P. (2016). *The ABCs of how we learn: 26 scientifically proven approaches, how they work, and when to use them*. London: W.W.Norton & Company.

Sundin, O. (2024, January 15). Webbinarium at Goto10 (Internetstiftelsen): AI och källkritiska utmaningar.

Sunstein, C. R. (2009). *Republic.com 2.0*. New Jersey: Princeton University Press.

Swann, W. B. (1989). Agreeable Fancy or Disagreeable Truth? Reconciling Self-Enhancement and Self-Verification. *Journal of Personality and Social Psychology*. *57*(5), 782-791.

Taekke, J. & Paulsen, M. (2017). Digitalisation of education - the theory of the three waves. *Papers from The Center for Internet studies*. Aarhus: Center for Internetforskning.

The Department of Education. (2014). *Science programmes: National curriculum in England. Department of Education*. https://www.gov.uk/government/publications/national-curriculum-in-england-science-programmes-of-study

The Swedish National Agency for Education. (2011, 2022). *Läroplan, program och ämnen i gymnasieskolan.* https://www.skolverket.se/undervisning/gymnasieskolan

Undervisningsministeriet. (2020). *Laereplaner 2020.*

https://www.uvm.dk/gymnasiale-uddannelser/fag-og-laereplaner/laereplaner-2020

Utbildningsstyrelsen. (2019). *Grunderna för gymnasiets läroplan 2019.* https://eperusteet.opintopolku.fi/#/sv/lukiokoulutus/6828810/tiedot

Wiblom, J., Rundgren, C.-G. & Andrée, M. (2017). Developing Students' Critical Reasoning About Online Health Information: A Capabilities Approach. *Research in Science Education*, *49*, 1759-1782. https://doi.org/10.1007/s11165-017-9674-7

Willingham, D. T. (2010). Critical Thinking: Why Is It So Hard to Teach? *Arts Education Policy Review*. *109* (4), 21-32. https://doi.org/10.3200/AEPR.109.4.21-32

Voogt, J., Roblin, N. P., Tondeur, J., & Fisser, P. (2012). Technological pedagogical content knowledge – a review of the literature. *Journal of Computer Assisted Learning*, *29*(2), 109-121. https://doi.org/10.1111/j.1365-2729.2012.00487.x

Örtegren, A. (2022). Digital citizenship in teacher education – Exploring

conceptualizations in a postdigital era. In J. Jaldemark, M. Håkansson, P. Lindqvist, L.-M. Mozelius, M. Öberg, N. De Laat, D. Bonderup, & T. Ryberg (Eds.), *Networked Learning 2022: Proceedings for the thirteenth International Conference on Networked Learning* (348-357). Networked Learning Conference Proceedings.

Appendix 1

Questionnaire: Digital Information Competence

A significant portion of the information processed in today's upper secondary school classrooms comes from various online sources. Learning in such an environment is demanding and places high demands on you as a student. This project aims to investigate how students search for, organize, and share information online to evaluate students' digital information competence. Your participation helps us understand how young people use the internet and how schools can support students in becoming critical users of online information.

1. Please indicate your gender:

Female – Male – Prefer not to answer

2. I am enrolled in the following program at upper secondary school:

3. I am currently in the following year at upper secondary school:

Year 1 – Year 2 – Year 3

4. I possess strong digital skills to effectively use the internet.

Always – Usually – Sometimes – Never

5. To me, having strong digital skills means:

6. I practice safe and responsible internet use.

Always – Usually – Sometimes – Never

7. To me, practicing safe and responsible internet use means:

8. Harmful online behavior, in my opinion, includes:

9. I consistently show respect for myself and others online.

Always – Usually – Sometimes – Never

10. To me, showing respect online means:

11. I find it easy to absorb information from a printed publication (analog).

Always – Usually – Sometimes – Never

12. I find it easy to absorb information from a website or online source (digital).

Always – Usually – Sometimes – Never

13. When I refer to credible information, I mean:

14. I can evaluate the credibility of information from a printed publication (analog).

Always – Usually – Sometimes – Never

15. I can evaluate the credibility of information from a website or online source (digital).

Always – Usually – Sometimes – Never

16. I can assess the credibility of information from a textbook (analog).

Always – Usually – Sometimes – Never

17. I can assess the credibility of a digital article online.

Always – Usually – Sometimes – Never

18. I trust information shared with me personally online (digital).

Always – Usually – Sometimes – Never

19. When I say I trust information shared with me personally online (digital), I mean:

20. I am responsible for verifying credibility online.

Always – Usually – Sometimes – Never

21. When I say I'm responsible for checking credibility online, I mean:

22. I find it easy to search for information in a textbook (analog).

Always – Usually – Sometimes – Never

23. When I say it's easy to search for information in a textbook (analog), I mean:

24. I believe I know what a search engine is.

Yes, absolutely sure - Yes, I think so - No, not sure - No, no idea

25. A search engine, to me, is:

26. I find it easy to search for information using a search engine (e.g., Google Chrome).
    Always – Usually – Sometimes – Never

27. When my friend and I search for the same concepts on our own computers (online), we get the same results.

    Always – Usually – Sometimes – Never

28. I believe the appearance of search results in online searches is influenced by:

29. I find it easy to navigate (locate information) on web pages.

Always – Usually – Sometimes – Never

30. I find it easy to navigate between web pages.

Always – Usually – Sometimes – Never

31. I understand the term "cookies."

Yes, absolutely - Yes, I think so - No, not sure - No, no idea

32. I believe "cookies" refer to:

33. I share information online.

Always – Usually – Sometimes – Never

34. I share my information online because:

35. I share my information online on the following platforms:

36. I share my information online because:

37. I take responsibility for what I share online.

Always – Usually – Sometimes – Never

38. Taking responsibility for what I share online means that I:

39. I frequently reconsider/change my opinion based on information I have searched for online.

Always – Usually – Sometimes – Never

40. I frequently reconsider/change my opinion based on information I have received/shared online.

Always – Usually – Sometimes – Never

41. Please provide examples of opinions you have reconsidered/changed when you found/received information shared online.