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The Usefulness of Science Knowledge and Science Education in the Lives of Non-Scientists

The EU Framework of Science Education for Responsible Citizenship (Hazelkorn et al., 2015) identified the main issues involved in "helping all citizens acquire the necessary knowledge of and about science to participate actively and responsibly in, with and for society, successfully throughout their lives" (p.7). Its first recommendation is that science education should be an essential component of a learning continuum for all, from pre-school to active engaged citizenship. Science education is seen in this report as vital to promoting a culture of scientific thinking and dispositions, and inspiring citizens to use evidence-based reasoning for decision making. This vision of science education corresponds closely to Roberts (2007) vision II of science literacy which refers to a curriculum looking 'outside of science' (Roberts & Bybee, 2014) by including skills and knowledge that lay people need to have to deal with science related problems in their daily lives, such as Ryder's (2001) "functional science literacy", and Fensham's notion of "connoisseurs of science" emphasizing citizen's ability to make judgments (Fensham, 2015).

In our editorial "Bridging science education and science communication research" (Baram-Tsabari & Osborne, 2015) Osborne and I put forward an observation: Science education makes the optimistic assumption that if science is taught properly, people who encounter science in their everyday lives can acquire the necessary knowledge to reach an informed, scientifically-based decision. However, empirical evidence from the field of public engagement with science indicates that people make meaning of the science they encounter in their lives using different narratives based on culturally relevant prior knowledge that may or may not include science (e.g., Carrion, 2017; Feinstein, 2014; Hine, 2012; Laslo, Baram-Tsabari, & Lewenstein, 2011; Layton, Jenkins, Macgill, & Davey, 1993).

Science literacy plays out in a social context in that social, cultural, and demographic differences influence how people engage with science, and what concerns and resources they have. People's own values, interests, and non-scientific knowledge shape their perspective. The weight people attach to underlying scientific vs. non-scientific knowledge when making decision is a function of this individual perspective (Scharrer, Rupieper, Stadtler, & Bromme, 2016). Science literacy can also be seen as a characteristic of the community with its division of cognitive labor (Scharrer et al., 2016), rather than as an individual characteristic. In Feinstein's (2015) account of the Lippmann-Dewey debate, both scholars agreed that the ignorance of individual citizens was an inevitable by-product of specialization, and the distracting demands of everyday life. Dewey's (1927) solution to healthy and informed civic participation in democracy was to address the level of communities rather than that of individuals: in a "well-functioning community an individual does not need to know about a particular topic as long as she is meaningfully connected to someone who does" (Feinstein, 2015) (p.156).

To be scientifically literate one needs to have the ability to make thoughtful decisions, which includes a critical assessment of scientific claims (e.g., Kolstø et al., 2006; Norris & Phillips, 1994; Ryder, 2001), especially in the media (McClune & Jarman, 2010). However, Norris

(1995), based on Hardwig (1985) argues that non-scientists cannot avoid some epistemic[1] dependence (Pritchard, 2015) on experts: "non-scientists' belief or disbelief in scientific propositions is not based on direct evidence for or against those propositions, but, rather, on reasons for believing or disbelieving the scientists who assert them" (p.206). This epistemic dependence is further explained by Bromme (Bromme & Goldman, 2014;
Bromme, Kienhues, & Porsch, 2010) who noted that laypeople frequently have to judge the validity of scientific knowledge claims that are of great relevance to their lives, but they lack the necessary epistemic capabilities to make such judgments adequately. Therefore, the ability of laypeople to reach informed decisions is usually based not on a first hand evaluation of what is true but on a second hand evaluation of "who knows what and whom to trust" (Bromme & Goldman, 2014). These and other studies led Bromme and Goldman (Bromme & Goldman, 2014) to argue based on the theory of bounded rationality (Kahneman, 2003) that the public's limited understanding of science leads people to make science related decisions mostly by using quick heuristics, a phenomenon they called a "bounded understanding of science". To complicate things even further, when science is popularized and seems easy to understand, the ease of processing leads readers to underestimate their dependence on experts (Scharrer et al., 2016). Furthermore, depending on the scientific topic, people appear to distinguish between what they judge to be credible and what they personally believe to be true (Bromme, Scharrer, Stadtler, Hömberg, & Torspecken, 2015).

It is not clear how much school science instruction improves children's pre-existing reasoning skills to make judgments about science expertise (Sandoval, Sodian, Koerber, & Wong, 2014). Other studies, however, show that *competent outsiders* are able to make sophisticated judgments about the credibility of scientific claims based on cues such as professional reputation, publication venue, institutional affiliation, and potential conflicts of interest, even when they do not understand the technical nuances of experimental designs or laboratory techniques (Feinstein, Allen, & Jenkins, 2013).

Science literacy in real life situations: What does the public engagement with science literature tell us?

On the one hand, the literature reports cases in which laypeople develop science-related expertise (Epstein, 1995), use science to become expert consumers and effective caregivers or patients (Feinstein, 2014; Shauli & Baram-Tsabari, 2018), and participate in scientific research, as in the growing field of citizen science (Bonney, Phillips, Ballard, & Enck, 2016; Lewenstein, 2016). An eminent case study (Wynne, 1996) of farmers' responses to scientific advice show laypeople capable of "extensive informal reflection upon their social relationships towards scientific experts, and on the epistemological status of their own local knowledge in relation to science as an `outside' knowledge" (p.281). It also demonstrated how the public uptake of science depends primarily upon the trust and credibility public groups place in scientific institutions and representatives (Wynne, 1996). On the other hand, this literature points to the marginality of science knowledge to non-scientists' decision making. In the foundational study *Inarticulate Science* (Layton et al., 1993), four cases in which laypeople had to cope with science-related situations were analyzed. The authors found that in all four cases, participants were rarely inclined to frame their challenges in terms of science (a conclusion echoed by (Feinstein, 2014)). The authors concluded that in order to become practical, science knowledge needs to be relevant to the person concerned, align with personal experience, relate to other social knowledge, and derive from a trustworthy source.

Our study of parents of hearing-impaired children explored their use of science knowledge in advocating for their children's rights (Shauli & Baram-Tsabari, 2018). Shauli and I found that

[1]Epistemic - relating to knowledge or to the degree of its validation. Epistemic dependence – the dependence of one's knowledge on factors outside one's cognitive agency [41], e.g. one does not possess direct evidence that smoking causes lung cancer, but believes so nonetheless [40].

parents use general science knowledge to construct and comprehend science knowledge in the field of hearing (e.g., what are soundwaves?), and that a lack of general science information hinders this process. We then investigated the quantitative interactions between general scientific knowledge, contextual scientific knowledge in the field of hearing, and parents' advocacy knowledge and attitudes. Based on 115 parents' questionnaires, general science knowledge was a predictor of contextual science knowledge, and parents who displayed higher contextual scientific knowledge emerged as having slightly better advocacy attitudes and knowledge. The small explained variance (5.5%) is consistent with previous research on knowledge and the prediction of behavior (Ajzen, Joyce, Sheikh, & Cote, 2011; Kaiser & Fuhrer, 2003).

In the last ten years, the internet in general, and social networking sites in particular, have become a primary source for science and technology related information (National Science Board, 2016; Oz, 2015), discussion and deliberation (Brossard, 2013; Brossard & Scheufele, 2013), and a place to go to for advice and emotional, social and psychological support (Zillien, Haake, Fröhlich, Bense, & Souren, 2011). Many of the insights regarding public engagement with science are replicated online (e.g., (Betten, Broerse, & Kupper, 2017)). However, the new media also have special attributes that shape the ways in which public engagement with science plays out (Brossard, 2013; Brossard & Scheufele, 2013; Peters, Dunwoody, Allgaier, Lo, & Brossard, 2014). The new media landscape is characterized by an abundance of content, interactivity, mobility, and multimediality (Schejter & Tirosh, 2016). Each of these is a double-edged sword enabling new affordances, while making it harder for a non-expert audience to reach an informed science related decision (Baram-Tsabari & Schejter, forthcoming), especially in a context where false news spreads further and faster than truth (Vosoughi, Roy, & Aral, 2018) and science and health communication is being weaponized for political reasons (Broniatowski et al., 2018).

Our study of polio vaccination discussions in a *Facebook* group found that although half the items addressed scientific or medical topics as their primary topic, most items (96%) did not present any evidence to support their arguments. That was also true for the physicians who took part in the discussion. Reasoning with evidence did not seem to be a natural part of the online informal discussion, although it mainly revolved around science (Orr & Baram-Tsabari, 2018). This raises issues regarding the attainability of the learning goal "engaging in argument from evidence" outside the classroom. Our analysis (Laslo & Baram-Tsabari, submitted) of expressions of science literacy in readers' comments about online science related coverage found that over half of the scientific concepts used by the commentators were at the high school or academic level, in which science is elective. Thus, in order to participate in the discussion or even just follow it passively, members of the public need to learn many new science concepts independently. Similarly, Shea (Shea, 2015) found that the knowledge needed to understand news articles about genetics exceeds what is expected by the relevant learning progression in schools. More importantly, in several studies of online authentic discussions (Asakly, Orr, & Baram-Tsabari, 2016; Laslo & Baram-Tsabari, submitted; Orr & Baram-Tsabari, 2018; Orr, Baram-Tsabari, & Landsman, 2016) we found that expressions of science literacy did not necessarily go hand-in-hand with the scientific consensus. Scientific knowledge was often used to support beliefs which were at odds with the scientific consensus. These findings challenge the ‘deficit model’, which sees scientific illiteracy as the root cause of opposition to the scientific consensus.

Although it is tempting to assume that individuals who do not accept the scientific consensus are anti-science or simply uninformed, empirical data do not support this notion. Health related issues demonstrate mixed findings: while high health literacy was significantly correlated with positive outcomes (e.g., use of more varied children's weight control strategies) (Liechty, Saltzman, Musaad, & Team, 2015), parents with relatively high scores on a health literacy questionnaire were more likely to be opposed to childhood vaccination (Aharon, Nehama, Rishpon, & Baron-Epel, 2017). More generally, an influential meta-analysis found that individuals with greater science literacy are more likely to report positive attitudes toward science (Allum, Sturgis, Tabourazi, & Brunton-Smith, 2008). However, other subsequent studies in the US context showed that where ideology-related science controversies are studied, gaps in opinions are typically larger among individuals with more years of formal education (e.g., Kahan et al., 2012). In a PNAS article (2017) a secondary analysis of a large nationally representative US based survey revealed that where religious or political polarization existed (stem cell research, the Big Bang, human evolution, and climate change), it was greater among individuals with more general education and among individuals with greater scientific knowledge, as measured by both science course attainment and scores on a science literacy test.

This phenomenon is mainly attributed to motivated reasoning, in which people seek, evaluate, interpret, and recall information in ways that support their beliefs and commitments (Kunda, 1990). Education and specific knowledge of the content area give people a more elaborate toolbox to interpret evidence in support of their preferred conclusions. Better educated people may be more likely to know when political or religious communities have chosen sides on an issue, and hence what they should think about it. Finally, educated individuals may also have greater confidence in their own knowledge (Drummond & Fischhoff, 2017). To conclude with the sobering words of Mezirow (Mezirow, 1990): "In reality…we never have complete information, are seldom entirely free from external or psychic coercion of some sort, are not always open to unfamiliar and divergent perspectives, may lack the ability to engage in rational and critically reflective argumentation…and only sometimes let our conclusions rest on the evidence and on the cogency of the arguments alone" (p.7). This depiction is far from the optimistic, even naïve, view of science education that if we teach science well, people will be making evidenced-based decisions about science related issues.

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