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2020

Ho, S. S., Looi, J., Leung, Y. W., Bekalu, M. A., & Viswanath, K. (2020). Comparing the knowledge gap hypothesis in the United States and Singapore : the case of nanotechnology. Public Understanding of Science, 1–20. doi:10.1177/0963662520952547

https://hdl.handle.net/10356/143752

https://doi.org/10.1177/0963662520952547

Comparing the Knowledge Gap Hypothesis in the United States and Singapore: The Case of Nanotechnology

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This is the final version of a manuscript that appears in *Public Understanding of Science.* The APA citation for the published article is:

Ho, S. S., Looi, J., Leung, Y. W., Bekalu, M. A., & Viswanath, K. (2020). Comparing the knowledge gap hypothesis in the United States and Singapore: The case of nanotechnology. *Public Understanding of Science*, 1–20. https://doi.org/10.1177/0963662520952547

Acknowledgements

The author(s) thank Agnes S.F. Chuah and the three anonymous reviewers for their helpful comments on this work.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the NTU-HSPH Initiative for Sustainable Nanotechnology (Grant Number 17002).

Supplemental material

Supplemental material for this article is available online.

Abstract

This study examines the knowledge gap hypothesis in the United States and Singapore in the context of nanotechnology. This study proposes that academic discipline serves as a better indicator than education levels in predicting nanotechnology knowledge gaps. To reflect the contemporary media landscape, this study examines how attention to online media and documentaries alongside traditional news outlets affect individuals' nanotechnology knowledge. In both countries, online media and documentaries, as well as traditional news outlets, were related to nanotechnology knowledge to various extents. While the knowledge gap hypothesis was not observed in Singapore, results revealed that increased media attention and interpersonal discussion widened knowledge gaps between individuals from science and non-science disciplines in the United States. Education levels failed to reveal a consistent moderation effect. Taken together, the interaction analyses revealed that academic discipline predicted nanotechnology knowledge gaps more consistently than education levels in the United States. Theoretical and practical implications are discussed.

Keywords: knowledge gap hypothesis, mass media, nanotechnology, public opinion, risk perception

Comparing the Knowledge Gap Hypothesis in the United States and Singapore: The Case of Nanotechnology

The allocation of government funds for novel science and technology, such as nanotechnology, is largely influenced by public opinion. A large body of research has examined the role of value predispositions, suggesting that risk and benefit perceptions, religiosity, and deference to science play important roles in shaping support (e.g. Ho et al., 2008, 2010; Liang et al., 2015). However, several other studies have provided evidence that knowledge, to a smaller extent, could shape public attitudes toward science and technology (e.g. Buykx et al., 2015; Ho et al., 2010). Raising public knowledge is important in helping individuals make informed policy decisions (Retzbach et al., 2011; Schoenfeld, 2010). Moreover, raising awareness can nurture an informed public by clarifying their doubts and misunderstanding about nanotechnology (Grimes, 2016). Insufficient knowledge about a technology can foster apprehension toward it (Allum et al., 2008), reducing support and subsequently the degree to which society can benefit from technological advancements (Su et al., 2014). Despite the benefits of achieving a knowledgeable citizenry, knowledge is often not disseminated equally among individuals from different socioeconomic status (SES), resulting in knowledge gaps. Societal inequalities in knowledge distribution may challenge advancements in science and technology.

The knowledge gap hypothesis (Tichenor et al., 1970) explains this inequitable distribution, by positing that increasing media attention and discussion about issues will not benefit everyone equally. Individuals with higher SES are better equipped to acquire, receive, and process information than individuals with lower SES (Cacciatore et al., 2014). Therefore, increasing media attention and discussion about issues widens the knowledge gap between the two SES groups.

This study seeks to extend the knowledge gap hypothesis in several ways. First, this

study considers the role of non-news media in shaping nanotechnology knowledge. While prior research specifically examines SES indicators and attention to news media as indicators for nanotechnology knowledge, this study includes attention to online media and attention to documentaries. Second, this study seeks to assess the suitability of utilizing academic discipline as a predictor of nanotechnology knowledge gaps. Knowledge gap hypothesis studies have typically utilized education levels as a proxy for SES and a predictor of knowledge gaps. However, nanotechnology is a complex and novel topic, and most individuals may not acquire knowledge about nanotechnology during their formal education. Hence, this study endeavors to extend the knowledge gap hypothesis by using academic discipline to address the potential shortfalls of education level as a predictor of nanotechnology knowledge gaps. Third, this study seeks to compare the knowledge gap hypothesis in the United States and Singapore. As most studies are conducted in the United States, this cross-national comparison may unveil how knowledge gaps can be narrowed. The United States and Singapore were selected for cross-national comparison due to their economic resources and technological expertise, which are essential for nanotechnology developments.

Despite this, the United States and Singapore possess starkly different education structures and media systems. Generally, students across the United States attend elementary school, middle school, and high school before finally attending vocational training, community college, or undergraduate programs (National Center for Education Statistics, 2003). In addition to this nationwide education system, the federal, state, and district are able to influence education curriculums (Herr, n.d.). In comparison, students in Singapore attend primary school before deciding whether they will pursue secondary schools in mainstream or special education schools focused on sports and arts. After completion of their secondary education, students choose between attending the Institute of Technical Education,

polytechnics, or junior colleges. Students who complete their polytechnic or junior college education then have the option of furthering their studies in universities (Ministry of Education, 2020). Despite the variety of education choices, Singapore possesses a homogeneous education system with a streamlined education curriculum (Ministry of Education, 2020).

While media coverage across both countries mostly convey a neutral or positive tone toward nanotechnology (Fiske et al., 2014; Friedman and Egolf, 2005; Gaskell et al., 2005), there are many more media outlets available in the United States than in Singapore (BBC, 2019; Ministry of Communications and Information, 2019), providing audiences with more options in terms of media content. Further, the United States prides itself on press freedom (Bikales, 2018), while Singapore does not subscribe to the Western liberal press model (National Archives of Singapore, 2005).

1. Theoretical approach

Tichenor et al. (1970) proposed the knowledge gap hypothesis to account for the inequitable distribution of information and discrepancies in knowledge levels among individuals with different SES. The knowledge gap hypothesis first posits that individuals from higher SES will have more knowledge than individuals from lower SES. This is because high SES individuals tend to have higher education than low SES individuals, resulting in increased exposure to and understanding of more issues. Furthermore, individuals from high SES tend to have different media preferences from individuals with low SES, which could lead to differential exposure to information (Tichenor et al., 1970). Compared to individuals from low SES, those from high SES also tend to have more access to relevant social contacts with whom they can discuss new topics (Bonfadelli, 2002).

Socioeconomic status. Socioeconomic status (SES) is commonly indicated by individuals' education (Ho, 2012; Tichenor et al., 1970; Yang and Ho, 2017) and income (Su

et al., 2014). The knowledge gap hypothesis rests upon the assumption that individuals' knowledge depend on their SES (Tichenor et al., 1970). That is, individuals with higher SES possess more knowledge than those with lower SES (Hwang and Jeong, 2009). These knowledge gaps among individuals with varying SES have been extensively observed in health and science communication research. Studies have demonstrated a positive relationship between individuals' education and their knowledge in the United States (Viswanath et al., 2006) and in Singapore (Ho, 2012). Income was positively related to individuals' knowledge (Ho, 2012), as individuals with higher incomes had greater exposure to information sources and higher self-efficacy for information-seeking (Ishikawa et al., 2012; Viswanath and Ackerson, 2011). Thus, we posit:

H1. Education is positively associated with nanotechnology knowledge.

H2. Income is positively associated with nanotechnology knowledge.

Academic discipline. Since nanotechnology is a niche and emerging technology, nano-specific information may not yet be incorporated in formal science education curriculums. Thus, education levels might not be indicative of knowledge levels. Instead, nanotechnology knowledge may only be acquired when individuals specialize in science academic disciplines during their higher education. That is, individuals who specialize in non-science disciplines might not know much about nanotechnology even if they attained a postgraduate degree. For example, a professor in literature might have less knowledge about nanotechnology than an undergraduate studying material science. Hence, for emerging topics, we propose academic discipline as a better indicator of knowledge, rather than generic education levels.

H3. Individuals from science academic disciplines will possess more nanotechnology knowledge than individuals from non-science academic disciplines.

Media attention. While formal science education is imperative in raising public

awareness, its long-term effectiveness is limited once individuals complete their formal education (Falk et al., 2007). The mass media plays a vital role in disseminating information and sustaining public interest in science and technology (Falk et al., 2007). Since the mass media serves as one of the key information sources for majority of the general public (Ho et al., 2011, 2012), governments have leveraged its extensive reach to raise public awareness of nanotechnology (European Commission, 2005). Numerous studies have attested that individuals who pay greater attention to television news or newspapers will acquire more knowledge (Ho et al., 2007, 2013; Slater et al., 2009; Su et al., 2014).' We posit:

H4. Attention to television news is positively related to nanotechnology knowledge.

H5. Attention to newspapers is positively related to nanotechnology knowledge.

While existing research on the knowledge gap hypothesis has examined individuals' attention to news media, individuals do not solely acquire and receive information from news stories (Baum, 2005). In fact, Newman et al. (2017) found that a growing number of individuals refrained from directly engaging with the news. Rather, individuals turn to online sources as their first and primary source of information (Ho et al., 2019). Another study revealed that individuals increasingly turned to non-news media via online platforms (e.g. social networking sites) as an information source (Westerman et al., 2014). For instance, individuals typically turn to search engines such as Google to gather information from different sources (e.g. subject experts or critics) instead of merely obtaining information from news sources (Toff and Nielsen, 2018). Even if individuals utilize social media solely for entertainment purposes, they still receive a substantial amount of unsolicited information (Toff and Nielsen, 2018). Since individuals can actively acquire information about nanotechnology from search engines as well as passively receiving nanotechnology-related information while browsing through their social media feeds, we posit that

H6. Attention to online media is positively associated with nanotechnology knowledge.

The rise of infotainment as a key information source (Nisbet and Scheufele, 2009) inspired this study to examine the role of documentaries in shaping knowledge. *Infotainment*, otherwise termed as "edutainment," refers to a hybridized media genre that delivers information using narratives to entertain and engage audiences. Individuals who do not consume news media are typically exposed to public affairs through infotainment programs, including talk shows and documentaries (Baum, 2005; Moy et al., 2005). Notably, the Pew Project on Excellence in Journalism (2008) revealed that individuals pay more attention to comedy news programs for science and technology topics compared to mainstream news outlets. Individuals may rely on infotainment programs as an information source about prominent societal issues (e.g. national policies, technological innovations) while deriving entertainment. Increased attention to infotainment programs, particularly documentaries, may therefore expose individuals to a greater amount of unsolicited nanotechnology-related information while fulfilling their needs for entertainment. Hence, we hypothesize that

H7. Attention to documentaries is positively associated with nanotechnology knowledge.

Interpersonal discussion. This study contends that interpersonal discussion is a vital information source for obtaining nanotechnology knowledge. In a meta-analysis, Gaziano (2010) classified the interpersonal context as a viable information dissemination channel and suggested studies to examine its effect on knowledge separately. In the era of information overload (Berghel, 1997), interpersonal discussion aids individuals in gaining awareness of breaking news stories amid the clutter of content (DeFleur, 1987; Ho, 2012; Katz and Lazarsfeld, 1955). When individuals partake in interpersonal discussion with their friends and family or community organizations, they are exposed to more information (Ho et al., 2010). Indeed, past studies have elucidated the unique role that interpersonal discussion has on knowledge in the case of the flu pandemic (Ho, 2012) and a variety of science issues (Ho et al., 2010). Hence, we postulate that

H8. Interpersonal discussion is positively associated with nanotechnology knowledge.

Amplifying the knowledge gap

Although Lee and Ho (2015) noted that individuals' attention to media outlets may be directly associated with their knowledge, the moderating influence of SES indicators may result in differing effects across media outlets. As compared to individuals from low SES, individuals from high SES tend to have more access to relevant social contacts with whom they can discuss new topics (Bonfadelli, 2002). Besides this, individuals from high SES tend to have different media preferences than those from low SES, which could lead to differential exposure to information (Tichenor et al., 1970). Hence, this study follows existing research by separately assessing the different media outlets (television news, newspaper, online media, documentaries, and interpersonal discussion).

The knowledge gap hypothesis further stipulates that instead of resulting in a more equally informed society, increased media attention to issues would widen the knowledge gap between individuals from high and low SES (Tichenor et al., 1970). Specifically, individuals from high SES will benefit from increased media attention and interpersonal discussion more than those from low SES (Bonfadelli, 2002; Tichenor et al., 1970). The knowledge gap hypothesis explains that individuals from higher SES tend to have more education and are therefore better able to seek, comprehend, and retain new information. Additionally, individuals with higher SES possess greater access to information sources than those from lower SES. Individuals with higher SES are able to gain more knowledge when they pay attention to information disseminated through television news, newspapers, online media, and documentaries (Bonfadelli, 2002; Tichenor et al., 1970). Similarly, individuals from higher SES would be better able to gain knowledge than those from low SES since they have greater exposure to information provided by influential others (Bonfadelli, 2002; Tichenor et al., 1970). Hence, as mass media increasingly infiltrates our daily lives, the knowledge gap

between those with high and low SES would widen instead of narrow (Griffin, 1990; Tichenor et al., 1970).

Yet, some recent studies revealed instances where increased media attention reduced knowledge gaps between individuals from high and low SES (e.g. Cacciatore et al., 2014; Ho, 2012). For instance, attention to online science news (Cacciatore et al., 2014), television (Cacciatore et al., 2014; Ho, 2012), and engagement in interpersonal discussion (Ho, 2012) narrowed the knowledge gaps between individuals from different SES. Attention to newspapers did not significantly affect discrepancies in knowledge among individuals with different SES (Cacciatore et al., 2014; Ho, 2012). Su et al. (2014) also revealed that attention to television news did not significantly influence knowledge gaps between individuals from different SES. Therefore, this study raises the following research question:

RQ1. How would education levels moderate the relationship between media attention to (a) television news, (b) newspapers, (c) online media, (d) documentaries, and (e) engagement in interpersonal discussion and individuals' nanotechnology knowledge to widen or narrow the knowledge gap?

Challenging the role of education as a key predictor of the knowledge gap, this study introduces academic discipline as a better predictor of knowledge gaps about emerging science issues. Since individuals from science academic disciplines would be equipped with prior knowledge, they would be more adept in acquiring, processing, and retaining information about science issues than individuals from non-science academic disciplines. Furthermore, individuals from science academic disciplines are likely to pay attention to scientific media more than individuals from non-science academic disciplines. Individuals from science disciplines would also be better able to engage in more frequent and in-depth discussions about science topics with other individuals from science disciplines, relative to those from non-science academic disciplines. Therefore, individuals from science academic

disciplines might benefit more from the media and interpersonal discussion than individuals from non-science academic disciplines. We raise the following research question:

RQ2. How would academic discipline moderate the relationship between media attention to (a) television news, (b) newspapers, (c) online media, (d) documentaries, and (e) engagement in interpersonal discussion and individuals' nanotechnology knowledge to widen or narrow the knowledge gap?

2. Cross-cultural comparison: The United States and Singapore

The knowledge gap hypothesis presents an unfortunate situation where increased media attention and interpersonal communication widens the separation between individuals from high and low SES. This study seeks to examine if the knowledge gap hypothesis will manifest differently in contexts with different media systems. To do so, this study conducts a cross-cultural comparison between the United States and Singapore.

The media in the United States and Singapore adopt different systems. The United States prides itself on their press freedom (Bikales, 2018) and journalists have the right to prevent Congress from interfering in the process of news making (Congress, 1791). On the contrary, national leaders in Singapore have stated that Singapore media should prioritize the national imperatives of maintaining social harmony and focus on public education instead of pursuing the Western liberal press model (Lee, 2000; National Archives of Singapore, 2005). Furthermore, the United States is geographically larger than Singapore—the United States is 9.8 million km^2 in size, while Singapore is 721.5 km^2 in size. In the United States, with states having access to different media outlets, individuals from different states may view different media content. This is in vast contrast to Singapore, where the population can access the same free-to-air television channels and newspapers, allowing everyone access to the same media content.

Despite the differences in media systems, the United States and Singapore possess

several cross-national similarities in terms of news coverage about nanotechnology. Content analyses in extant literature has consistently revealed that journalists in the United States typically provided positive coverage about nanotechnology (Fiske et al., 2014; Friedman and Egolf, 2005; Gaskell et al., 2005). In comparison, a content analysis of 155 news articles from *The Straits Times*— Singapore's English-language daily newspaper with the highest local readership—revealed that media coverage on nanotechnology between January 2013 and September 2018 was mostly neutral or favorable of nanotechnology[1].

Noting the central role of the media in the knowledge gap hypothesis, it is worthwhile to compare how the knowledge gap hypothesis might manifest differently in two countries with vastly different media systems. Therefore, we ask,

RQ3. How does the knowledge gap hypothesis differ between the United States and Singapore?

3. Method

Participant recruitment and sampling techniques

Nationally representative surveys were collected between July 2018 and September 2018 in the United States and Singapore. In the United States, we collected 1027 completed responses provided by an online panel maintained by GfK Knowledge Networks, achieving a completion rate[2]of 48.7%. The panel provided and maintained by Gfk Knowledge Networks is probability-based and is close to nationally representative of the US population. We also assigned weights to the participants to account for the lack of representativeness of individuals who fall under the federal poverty line. In Singapore, we hired Q Research Consulting to collect 1000 completed door-to-door survey responses with a 55.6% completion rate. To ensure that the Singapore sample was nationally representative, a

[1] We amassed the 155 news articles via LexisNexis using the search term "nanotechnology" to understand the Singapore media's general reporting regarding this topic. The news articles were independently categorized by two coders based on whether it conveyed a positive, neutral, or negative tone about nano-enabled food in Singapore. A high intercoder reliability was obtained between the coders (Cohen's kappa = .89).

[2] Completion rate = Number of completed responses/Number of eligible participants approached.

randomized list of addresses was purchased from the Department of Statistics Singapore. We used the next-birthday method to select participants from selected households.

Study procedure

Informed consent was obtained from all the participants in both countries prior to data collection. Before answering the survey questionnaires, participants were first exposed to a brief definition of nanotechnology[3] and nano-enabled food[4]. This approach helped participants accurately assess their attention toward information about nanotechnology across different news media. Upon completion of the survey questionnaires, participants from both countries received points from the survey panel and data collection providers, which could be exchanged for research incentives (e.g. shopping mall vouchers).

Measures

The exact item wordings are presented in Supplemental material. All items were measured using a 5-point Likert-type scale unless otherwise stated. Additional information about the questionnaire development procedure for "academic discipline" can also be found in Supplementary material.

Demographic variables. Gender (Female_{US} = 51.5%, male_{US} = 48.5%; female_{SG} = 51.5%, male_{SG} = 48.5%) and age (Median_{US} = 48.5 years, SD_{US} = 17.43; Median_{SG} = 44.0 years, SD_{SG} = 16.20) were used as control variables. Participants' combined annual household income was measured (Median_{US} = US$60,000–US$74,999; Median_{SG} = S$60,000–S$69,999). Participants were asked to indicate the highest education level that they had completed (Median_{US} = 5.00 or "High school graduate (high school diploma)/Some college (no degree)," SD_{US} = 1.47; Median_{SG} = 5.00 or "GCE 'A' levels," SD_{SG} = 1.89).

[3] Nanotechnology refers to a type of technology that is able to reduce particles to extremely small sizes at the nano scale. The diameter of a strand of hair is about 100,000 times larger than 1 nm. Such technology can be applied to many products, such as textile, electronic appliances, sports equipment, food (e.g. health supplements), and food-related products (e.g. food packaging). For example, silver nano-particles are added to some clothing to kill bacteria.

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Besides education level, participants indicated their specific academic discipline ($Science_{US}$ = 34.2%, $Non\text{-}science_{US}$ = 65.8%; $Science_{SG}$ = 28.1%, $Non\text{-}science_{SG}$ = 71.9%).

Attention to television, newspapers, online media and documentaries. Participants' attention to television, newspapers, online media and documentaries were each measured using three items adapted from Lee and Ho (2015). The content included television news, news articles, online articles or documentaries about (1) science and technology, (2) the harms of nano-enabled food, and (3) the benefits of nano-enabled food. The three items were averaged to create a composite index for each medium, where a higher score represents greater attention to nanotechnology in newspapers, online media and documentaries (Table 1).

[Insert Table 1 about here.]

Interpersonal discussion. Participants' engagement in interpersonal discussion was measured using five items adapted from de Zuniga et al. (2012). The items included frequency of discussions about nanotechnology with friends and family, co-workers and acquaintances, strangers, people with similar attitudes, and people with opposing viewpoints. The five items were averaged to create a composite index, where a higher score represents greater attention to newspapers on nanotechnology (M_{US} = 1.28, SD_{US} = 0.68, Cronbach's α_{US} = .94; M_{SG} = 1.31, SD_{SG} = 0.62, Cronbach's α_{SG} = .92).

Nanotechnology knowledge. Participants answered five true-false statements on nanotechnology adapted from past studies (Cacciatore et al., 2014; Su et al., 2014). Participants received one point for each correct answer, and zero points for wrong answers or if they did not know the answer. Participants could obtain between zero and five points in total by summing up the scores and a higher score represents a higher level of nanotechnology knowledge (M_{US} = 1.72, SD_{US} = 1.50, $KR\text{-}20_{US}$ = .70; M_{SG} = 2.19, SD_{SG} = 1.57, $KR\text{-}20_{SG}$ = .72).

Analytical approach

To test our hypotheses, RQ1 and RQ2, we conducted two hierarchical linear regression analyses. We computed interaction terms by multiplying the standardized values of education and academic discipline with science communication variables. Separate regression models were conducted for each country. For each regression model, control variables were entered into the first block; socioeconomic status variables were entered into the second; media attention and interpersonal discussion variables were entered into the third; and interaction terms were entered into the fourth block.

Finally, to answer RQ3, we wanted to test whether the relationships were significantly different across countries. We compared the regression coefficients across both countries for when the variable is significantly associated with nano-specific knowledge in at least one country. We applied the formula $Z = (b_1 - b_2)/\sqrt{SEb_1^2 + SEb_2^2}$ to compare regression coefficients across samples (Paternoster et al., 1998). The strength of the relationships was regarded as significantly different if the magnitude of the z-score attained was more than 1.96.

4. Results

The regression analyses accounted for 28.40% of variance for nanotechnology knowledge in the United States and 11.6% of variance for nanotechnology knowledge in Singapore (Table 2).

[Insert Table 2 about here.]

Main effects

SES. Education was positively associated with nanotechnology knowledge in both the United States (β_{US} = .11, p < .001) and Singapore (β_{SG} = .19, p < .001), supporting H1. Income was positively associated with nanotechnology knowledge in the United States (β_{US} = .07, p < .05), but this relationship was not significant for Singapore (β_{SG} = .05, p > .05),

providing partial support for H2. Individuals from science academic disciplines possessed higher levels of nanotechnology knowledge than individuals from non-science academic disciplines in the United States (β_{US} = .13, p < .01), but not in Singapore (β_{SG} = −.05, p > .05), partially supporting H3.

Media attention. The results revealed that media attention did not consistently yield positive significant associations with nanotechnology knowledge across different media channels and outlets. Attention to television news was significantly associated with nanotechnology knowledge in the United States (β_{US} = .12, p < .05), but not significantly related to nanotechnology knowledge in Singapore (β_{SG} = .00, p > .05), partially supporting H4. Attention to newspapers was not significantly associated with nanotechnology knowledge in both the United States (β_{US} = −.04, p > .05) and Singapore (β_{SG} = −.02, p > .05), rejecting H5. Attention to online media was significantly associated with nanotechnology knowledge in both the United States (β_{US} = .18, p < .01) and Singapore (β_{SG} = .12, p < .01), supporting H6. Similarly, attention to documentaries was significantly associated with nanotechnology knowledge in both the United States (β_{US} = .23, p < .001) and Singapore (β_{SG} = .14, p < .001), supporting H7. Contrary to predictions, interpersonal discussion was negatively associated with nanotechnology knowledge in the United States (β_{US} = −.19, p < .001), but this negative association did not attain statistical significance in Singapore (β_{SG} = −.04, p > .05). Hence, the data failed to support H8.

Interaction effects

Education. RQ1 examined how education would moderate the relationship between nanotechnology knowledge and media attention as well as engagement in interpersonal discussion. No interaction effects were observed in Singapore, suggesting that increased media attention and interpersonal discussion neither widened nor narrowed the knowledge gap among individuals with more education and individuals with less education.

In the United States, the results revealed that more interpersonal discussion reduced individuals' nanotechnology knowledge. Interaction analysis revealed that education significantly moderated the relationship between interpersonal discussion and nanotechnology knowledge ($\beta_{US} = .09$, $p < .01$; Figure 1). Specifically, nanotechnology knowledge reduced less among individuals with more education than individuals with less education, widening the knowledge gap.

[Insert Figure 1 about here.]

Academic discipline. RQ2 examines how academic discipline would moderate the relationship between nanotechnology knowledge and media attention as well as engagement in interpersonal discussion. The results revealed that academic discipline significantly moderated the relationships between all media attention variables and nanotechnology knowledge in the United States. Academic discipline moderated the relationship between nanotechnology knowledge and attention to television news ($\beta_{US} = .06$, $p < .05$), attention to newspapers ($\beta_{US} = .11$, $p < .001$), attention to online media ($\beta_{US} = .11$, $p < .001$), attention to documentaries ($\beta_{US} = .09$, $p < .001$), and interpersonal discussion ($\beta_{US} = .07$, $p < .05$).

As predicted, individuals from science disciplines gained more nanotechnology knowledge when they paid more attention to television news, newspapers, and online media. However, individuals from non-science disciplines did not gain significantly greater levels of nanotechnology knowledge when they paid more attention to television news and online media. Nanotechnology knowledge even decreased among individuals from non-science disciplines who paid more attention to stories on nano-enabled food via newspapers. Therefore, media attention widened the nanotechnology knowledge gap between individuals from different academic disciplines in the United States.

Attention to documentaries raised the levels of nanotechnology knowledge for both individuals from science disciplines and individuals from non-science disciplines. However,

individuals from science disciplines gained significantly more nanotechnology knowledge compared to individuals from non-science disciplines when they paid more attention to documentaries. Therefore, attention to documentaries widened the nanotechnology knowledge gap between individuals from different academic disciplines in the United States.

Contrary to predictions, individuals' nanotechnology knowledge decreased when they engaged in more interpersonal discussion. However, the interaction effects revealed that the dampening effects of interpersonal discussion were weaker among individuals from science disciplines than individuals from non-science disciplines. That is, nanotechnology knowledge reduced less among individuals from science disciplines than among individuals from non-science disciplines, resulting in a widening of the knowledge gap.

In Singapore, academic discipline failed to moderate the relationships between the media attention variables and nanotechnology knowledge. There was also no significant interaction for academic discipline and interpersonal discussion on nanotechnology knowledge.

Comparison of the knowledge gap hypothesis

Finally, RQ3 sought to examine how the knowledge gap hypothesis panned out differently in the United States and Singapore. As shown by the interaction effects, the knowledge gaps widened in the United States when media attention and interpersonal discussion were rampant. In Singapore, the knowledge gaps did not widen.

Comparing main effects across countries, results revealed that the relationship between age and nanotechnology knowledge was significantly different across the United States and Singapore ($Z = 2.26$). The relationship between academic discipline and nanotechnology knowledge was significantly different across the United States and Singapore ($Z = 2.57$). The relationships between attention to documentaries and nanotechnology knowledge differed significantly across the United States and Singapore ($Z = -2.08$), and the

relationships between interpersonal discussion and nanotechnology significantly differed across the United States and Singapore ($Z = 3.05$). The relationships between nanotechnology knowledge and gender, education, income, attention to television news, and attention to online media did not differ between the United States and Singapore.

5. Discussion

Overall, this study revealed that the knowledge gap hypothesis panned out differently in the United States and Singapore. While the knowledge gap widened with increasing media attention in the United States, no such widening of the knowledge gap was observed in Singapore. Where the knowledge gap hypothesis was illustrated, academic discipline was a better predictor of the widening of the knowledge gap than education levels. The study also indicates the importance of contemporary media outlets and formats, such as online media and documentaries. It also challenges the notion that more interpersonal discussion is useful to improving knowledge levels.

Knowledge gaps in contrast: The United States versus Singapore

The knowledge gap hypothesis warns that using different media and communication tools would ultimately widen, rather than narrow the gap between individuals with high and low SES. Indeed, the widening of the knowledge gap was illustrated in the United States. However, the widening of the knowledge gap was not observed in Singapore. Beyond this study, Ho (2012) found that attention to news did not widen the knowledge gap among the better and less educated in Singapore. Singapore could possibly serve as a case study for possible solutions to prevent the widening of the knowledge gap.

Donohue et al. (1975) argued that the knowledge gap hypothesis might be mitigated among smaller, more homogeneous communities. The media and education systems of Singapore could have contributed to the nation being more homogeneous than the United States. The United States has more media outlets than in Singapore, with 1300 daily

newspapers in the United States as compared to only nine daily newspapers in Singapore (BBC News, 2019; Ministry of Communications and Information, 2019), allowing US audiences more choices for the type of content they wish to view. Singapore has significantly fewer media outlets than the United States, resulting in more uniformed reporting of issues. Singapore also has a more homogeneous education system than the United States. Singapore has a streamlined education curriculum, ensuring that individuals, even those with lower education levels, possess basic scientific literacy and competencies to process science information (Ministry of Education, 2014). By incorporating science as a core subject in education institutes nationwide, all students are exposed to scientific principles and developments from early in their formal education (Ministry of Education, 2014). The streamlined science education curriculum across institutes in Singapore would also mitigate knowledge inequalities since students are equipped with the same education materials related to nanotechnology.

In the United States, the education system is more fragmented, as the federal, state, and district can influence the science education curriculum (Herr, n.d.). This system can result in drastic differences in the educational content students are exposed to, resulting in different knowledge levels across topics. For instance, there are some states in the United States that teach evolution, while others teach creationism (Berkman and Plutzer, 2010; Carr, 2017). Using Singapore as a case study provides some preliminary evidence of how nations can prevent the manifestation of a widening knowledge gap.

Academic discipline versus education levels

As the knowledge gap hypothesis was not supported in the Singapore context, this section addresses the findings in the US context. Compared to education levels, academic discipline was a better predictor of the knowledge gaps. This finding may be attributed to the complexity of nanotechnology. Since nanotechnology is a complex, niche, and emerging

topic, individuals from non-science disciplines may not possess the specialized skills to gain subject expertise. On the contrary, individuals from science disciplines may possess the skills and prior knowledge to process, comprehend, and master information related to novel technologies. Furthermore, individuals from science disciplines might be more interested in keeping up with the developments of emerging technologies compared to individuals from non-science disciplines. Hence, the media preferences of individuals from science disciplines and individuals from non-science disciplines might differ with respect to how much science and technology content they view.

This study encourages future research to compare the effectiveness of academic disciplines and education levels as a predictor of the knowledge gap pertaining to science topics of varying levels of complexity, controversy, and development. The role of academic discipline may extend beyond science issues. Future studies can also test how relevant academic disciplines might predict the knowledge gap in other complex issues.

The role of informal media outlets

The findings demonstrated that attention to online media and documentaries were positively associated with their nanotechnology knowledge across both countries. In comparison, the positive association between attention to television news and their nanotechnology knowledge was statistically significant for the United States, but not for Singapore. Attention to newspapers failed to yield a significant relationship with nanotechnology knowledge in both the United States and Singapore. These results indicate that non-news media outlets (e.g. online media and documentaries) are critical in affecting individuals' nanotechnology knowledge, much more so than conventional news media outlets. These findings concurred with existing literature (e.g. Pew Project on Excellence in Journalism, 2008; Westerman et al., 2014). Furthermore, the relationship between attention to documentaries and nanotechnology knowledge was significantly stronger in the United States

than in Singapore. This could be due to the state of nanotechnology research in the United States and Singapore, where the United States is more matured than in Singapore. Documentaries on nanotechnology in the United States might differ in coverage from that in Singapore. Therefore, future studies examining the knowledge gap hypothesis should incorporate more non-news media outlets to gauge its impact on individuals' knowledge gaps and its ability to widen or narrow knowledge gaps associated with SES discrepancies.

Dampening effects of interpersonal discussion. The findings demonstrated that interpersonal discussion reduced individuals' nanotechnology knowledge across both countries. This observation could be attributed to the low levels of prevailing nanotechnology knowledge in both countries (M_{US} = 1.72, SD_{US} = 1.50; M_{SG} = 2.19, SD_{SG} = 1.57). The results also revealed that this dampening effect was stronger in the United States than in Singapore. One plausible explanation could be due to the more rampant spread of misinformation about nanotechnology in the United States than in Singapore. The stronger dampening effect of interpersonal discussion in the United States could be due to lower prevailing nanotechnology knowledge in the United States than in Singapore. As such, interpersonal discussion may amplify the spread of misconceptions or inaccurate information about nanotechnology.

Individuals' academic discipline and education levels also effectively moderated engagement in interpersonal discussion on nanotechnology knowledge to widen knowledge gaps. Specifically, individuals from science disciplines may be less susceptible to the misconceptions or falsehoods propagated during interpersonal discussion due to their prior scientific training than individuals from non-science disciplines. Moreover, individuals with higher education levels may possess greater media literacy or critical thinking abilities to analyze and dismiss the misconceptions and inaccurate information about nanotechnology, relative to those with lower education levels. Future studies can conduct experiments to

examine the effectiveness of message strategies that can address and debunk potential misconceptions and falsehoods about nanotechnology. Future studies could also examine how interpersonal discussion about a relatively unknown topic can influence knowledge levels.

Theoretical and practical implications

The findings provide several theoretical advancements to the knowledge gap hypothesis. First, this cross-national study revealed that the knowledge gap hypothesis manifested differently across countries with different media and education systems, demonstrating the importance of examining macro-level considerations. The findings from this study might help to explain why the knowledge gap hypothesis was not supported by some studies, while being supported in others. The extent of media coverage and public discussion about the topic, nationwide science education and literacy, and the perceived level of controversy of the topic may account for the mixed findings obtained in extant literature. Considering the controversy surrounding this study's focus on nano-enabled food, the findings may be generalizable to other types of controversial technologies including genetically modified food, artificial intelligence, nuclear energy, or embryonic stem-cell research. Despite this, the findings cannot extend to non-controversial sciences to which individuals are generally receptive (e.g. renewable energy sources). Therefore, future research could study the knowledge gap hypothesis juxtaposing controversial and non-controversial topics.

Second, this study also re-assessed the role of SES indicators (e.g. education level and household income) in the knowledge gap hypothesis. The knowledge gap hypothesis posits education as an indicator of the knowledge gap partially because individuals with more education have better reading and comprehension skills. As basic education is more prevalent today and literacy rates are much higher than when the knowledge gap hypothesis was

proposed in the 1970s (United Nations Children's Fund, 2018), education levels may no longer be a clear indicator of individuals' comprehension and reading skills. Rather, other considerations (e.g. academic discipline) may function as a better predictor of the knowledge discrepancies and inequitable distribution of knowledge, especially pertaining to novel and complex topics such as issues pertaining to science and technology. The efficacy of academic discipline and education levels in affecting nanotechnology knowledge gaps attest to the importance of enhancing the national science education curriculum. In particular, policymakers may consider incorporating a brief introduction of emerging technologies (e.g. nanotechnology, artificial intelligence) in the national science education curriculum to increase knowledge for nanotechnology and other science issues.

Third, this study found that interpersonal discussion reduced individuals' nanotechnology knowledge, contradicting previous studies that found that interpersonal discussion increased knowledge levels. This finding reveals the importance of understanding current knowledge levels before any intervention is implemented. Interpersonal discussion not only helps to spread accurate information but also helps to spread misconceptions and inaccurate information. When there is an information vacuum about a topic, there is a high possibility for interpersonal discussion to spread misconceptions, rather than accurate information. Policymakers can provide avenues for clarifying and debunking misconceptions related to emerging science and technology issues.

Finally, the findings attested to the importance of examining non-news media. Since individuals do not primarily and exclusively seek and receive information from the news media, the inclusion of online media and documentaries reflect individuals' information acquisition patterns more accurately (Ladwig et al., 2012). Rather than relying heavily on news media, communication practitioners can use more of online media and documentaries to inform the public about issues.

Limitations and directions for future research

This study has several limitations, which can be addressed by future research. First, the cross-sectional nature of this study limited its ability to draw causal inferences from the variables of interest. As such, the findings in this study cannot determine if individuals' SES, academic discipline, media attention, and engagement in interpersonal discussion precedes their nanotechnology knowledge, or vice versa. Future studies can utilize longitudinal surveys or randomized controlled experiments to determine the causal relationships among the variables. Second, this study did not conduct a content analysis of the media content in the United States and Singapore. As such, this study cannot conclusively determine that the differences in relationships in the United States and Singapore were due to the differences in media content. Future studies can complement this study by providing a content analysis. Third, this study administered the surveys in different ways. This study utilized an online survey for data collection in the States and collected data in Singapore utilizing door-to-door surveys. However, the differences in survey techniques were mitigated as the survey questionnaires in both countries were nationally representative, yielded similar sample sizes, and asked the same set of questions. Finally, this study only accounted for individuals' attention to different types of media in light of the high Internet penetration rates in both countries (Statista, 2019, 2020). While this approach is commonplace in extant research about the knowledge gap hypothesis, future studies may consider examining both the accessibility and attention to different types of media.

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Tables and Figures

Table 1. Questionnaire wording and descriptive statistics for attention to newspapers, attention to online media, and attention to documentaries.

Attention to Media	M_{US}	SD_{US}	Cronbach's α_{US}	M_{SG}	SD_{SG}	Cronbach's α_{SG}
Attention to newspapers When reading newspapers, either print or online how much attention do you pay to news articles on (a) science and technology, (b) the harms of nano-enabled food, (c) the benefits of nano-enabled food?	1.80	0.97	.86	1.79	0.85	.80
Attention to online media When using the Internet, excluding news websites, how much attention do you pay to articles on (a) science and technology, (b) the harms of nano-enabled food, and (c) the benefits of nano-enabled food?	1.98	0.95	.81	1.94	0.84	.79
Attention to documentaries When watching documentaries, either online or offline, how much attention do you pay to stories about (a) science and technology, (b) the harms of nano-enabled food, and (c) benefits of nano-enabled food?	1.81	0.98	.82	1.63	0.86	.79

M_{US} and SD_{US} is mean and standard deviation for the US; M_{SG} and SD_{SG} is mean and standard deviation for Singapore.

Table 2. Regression analyses for factors predicting nanotechnology knowledge in the U.S. and Singapore

Variables	US	SG
	β	β
Block 1: Control variables		
Age	-.10**	.01
Gender (Male = 0, Female = 1)	-.03	-.07*
Incremental R^2 (%)	1.80***	3.30***
F-value	9.39***	17.18***
Block 2: SES variables		
Education	.11***	.19***
Academic discipline (Non-Science = 1, Science = 2)	.13***	-.05
Income	.07*	.05
Incremental R^2 (%)	9.00***	4.00***
F-value	24.62***	15.77***
Block 3: Science communication variables		
Attention to TV news	.12*	.00
Attention to newspapers	-.04	-.02
Attention to online media	.18**	.12*
Attention to documentaries	.23***	.14***
Interpersonal discussion	-.19***	-.04
Incremental R^2 (%)	14.70***	3.70***
F-value	34.67***	12.24***
Block 4: Interactions		
Education × Attention to TV news	.04	-.02
Education × Attention to newspapers	.06	-.03
Education × Attention to online media	.04	-.03
Education × Attention to documentaries	-.02	.01
Education × Interpersonal discussion	.09**	-.05
Academic discipline × Attention to TV news	.06*	.03
Academic discipline × Attention to newspapers	.11***	.01
Academic discipline × Attention to online media	.11***	.00
Academic discipline × Attention to documentaries	.09**	.01

Academic discipline × Interpersonal discussion	.07*	.01
Incremental R^2 (%)	2.90***	0.60
F-value	19.84***	6.44***
Total R^2 (%)	28.40***	11.6***

SES: socioeconomic status.

* $p < .05$, ** $p < .01$, ***$p < .001$.

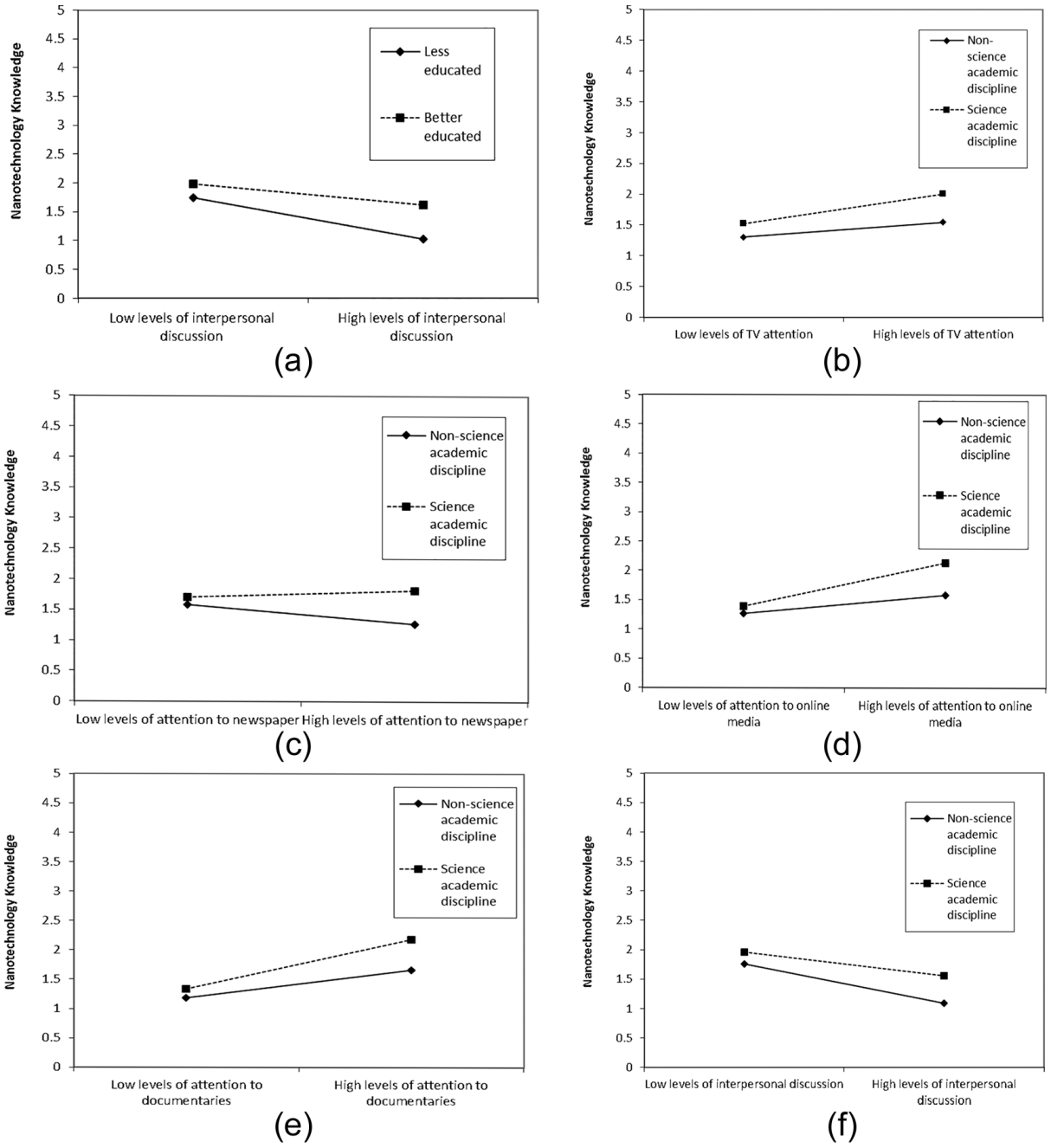

Figure 1. Interaction effects of independent variables on nanotechnology knowledge in the United States: (a) education and interpersonal discussion on nanotechnology knowledge, (b) academic discipline and attention to television news on nanotechnology knowledge, (c) academic discipline and levels of attention to newspapers on nanotechnology knowledge, (d) academic discipline and levels of attention to online media on nanotechnology knowledge, (e) academic discipline and attention to documentaries on nanotechnology knowledge, and (f) academic discipline and interpersonal discussion on nanotechnology knowledge.