Modeling South Korean Citizens' Quantification of COVID-19 Vaccination and Infection Risks Using Benchmark Values

Mina Gong
University of Georgia

Dru Horne
University of Georgia

Hyunkyoung Yoon
Arizona State University

Cameron Byerley
University of Georgia

During the COVID-19 pandemic, citizens have had to make new decisions about vaccination and social contact based on their personal risk estimates and the risk estimates of experts and governments. We analyzed survey data with 50 participants and interview data with three participants to model how South Korean citizens quantify risks associated with COVID-19 vaccination and infection and the severity and level of concern they associated with these percentages. We found participants' quantifications for COVID-19 risks and their meanings for their estimated risks are substantially different than experts. Participants used benchmarks such as 10% risk and 50% risk to estimate and reason about their COVID-19 risks.

Keywords: Probability, Understanding Percent Risk

Since the start of the COVID-19 pandemic, mathematics educators have been interested in contributing to the collective effort to reduce risk from COVID-19 using prior mathematics education research (Krause et al., 2021). Citizens' perceptions of risk play an important part in their choices, and their choices impact personal and societal risk (Raiffa, 1982). Doctors and epidemiologists often communicate risks with percentages, and mathematics educators are well positioned to study how citizens' make sense of this mathematical information. We know the concept of percentages (and the related concept of fractions) is difficult for many people, including those with undergraduate degrees and students taking advanced mathematics such as calculus (Byerley, 2019; Mullis et al., 1991; Wright, 2006). Specifically, the RUME community has an interest in preparing undergraduates to make sense of real-world mathematics as well as an interest in informal adult education about mathematics (SIGMAA on RUME, 2022). To contribute to this mission, we studied South Korean citizens' mathematical understanding of risks associated with COVID-19 vaccination and infection.

We focused on risk estimates related to both vaccination and infection because vaccine hesitancy is a top ten global health issue (World Health Organization, 2019; 2020). There is a statistically significant association between COVID-19 vaccination status and US citizens' perception of the relative risk of vaccination and infection (Yoon et al., 2022). The study found that US citizens who thought COVID-19 infection was less risky or equally risky than vaccination were less likely to be vaccinated than those who thought COVID-19 infection was more risky than vaccination. Even though the risks due to COVID-19 infection are orders of magnitude higher than the risks due to COVID-19 vaccination (CDC COVID-19 Response Team & Food and Drug Administration, 2021), only 48% of a random sample of US citizens thought COVID-19 infection was more risky than vaccination (Yoon et al., 2022).

In contrast to the previous study by Yoon and colleagues (2022), we used South Korean participants in this study. It is important to study real-world mathematical thinking in a variety of cultural contexts because much can be learned by investigating similar questions in contrasting

cultures (Stigler & Hiebert, 2009). The pandemic response, vaccination campaign, and mathematics education in South Korea are notably different from that in the United States. By early August 2022, more than 87% of the population in South Korea had been fully vaccinated and more than 65% had received booster shots (Korea Disease Control and Prevention Agency, 2022). Many South Korean citizens complain about social pressures to get a COVID-19 vaccine and believe the vaccination mandate is not reasonable despite the high vaccination rates (Han, 2022).

In order to better understand the South Korean public's vaccine hesitancy through a mathematics education lens, it is necessary to understand how citizens perceive the risks associated with COVID-19 infection and vaccination which are often expressed in percentages. Thus, this study investigates two research question: (1) How do South Korean citizens quantify their risk associated with COVID-19 infection and vaccination? and (2) What meanings do participants hold for their percentage estimates?

Literature Review and Theoretical Framework

Risk Perception

Risk has been defined as "a probability of an event combined with the magnitude of the losses and gain that it will entail" (Douglas, 2013) or a "probability-based forecast of the future" (Bernstein, 1996). Experts define risk based on relative frequency of occurrence, and while laypeople can assess frequency if asked, they tend to include other factors in their risk judgements (Covello et al., 1986, 1987; Slovic, 1987). These differences in the way the public and experts perceive risk can lead to miscommunication in which laypeople understand risk differently than experts or government agencies (Botterill & Mazur, 2004; Covello et al., 1986). For example, in the August, 2021 Gallup Poll, US citizens' mean estimate of the risk of dying from COVID-19 if infected and unvaccinated was higher than 50% (Rothwell & Witters, 2021), which differs dramatically from estimates by epidemiologists. Because, on average, citizens are giving such different estimates of risk than epidemiologists, it follows that their meaning for these percentages is likely different than that of epidemiologists. For example, citizens who estimated the mean risk of dying from COVID-19 if infected is 50% might disagree with the mathematically similar statement "half of the people who had COVID-19 died."

Risks in Frequency Formats and Percentage Formats

Prior research has shown that risks described in frequency formats (e.g., 10 of 100) are perceived as more serious than those in percentage formats (e.g., 10%) (Gigerenzer, 2011; Hoffrage et al., 2000; Slovic et al., 2000). Slovic et al. (2000) found that when assessing whether a hospitalized patient with mental disorder would harm others, people perceived a risk described with the frequency format, "20 out of 100 patients", as more serious than the same risk described in the percentage format, "20% of patients". Another study suggests expressing a small risk using a frequency format can frighten people because it is psychologically different from the same risk expressed as a percentage format (Purchase & Slovic, 1999). Another important aspect of understanding COVID-19 risk is numeracy which is defined as an individual's number sense and ability to understand and use numbers with concept of proportion, fractions, percentages, and probability (Dieckmann et al., 2009; Peters, 2012; Peters et al., 2006). Highly numerate people are more likely to be able to interpret the same risk presented in either frequency or percentage as equivalent (Peters, 2012; Peters et al., 2006). Exploring citizens' use of frequency format and percentage format may provide insight into how citizens understand probabilities when estimating risks associated with COVID-19 infection and vaccination.

Using Benchmark Values to Estimate Probability

Benchmarks are initial values that function as a point of reference to compare, assess, and adjust estimates of probabilities. We use the term *benchmark value* in this work to describe percentages that citizens' use frequently and easily assign meaning to. Citizens often use benchmark values as a point of reference, and they adjust estimates up or down from these values. Tversky (1974) suggests that when estimating the probability of an uncertain event, people tend to use a starting value and adjust it to produce the final estimates. Then, different initial values result in different estimates; if the starting point is too high or too low, the subsequent adjusting process yields a final answer that is close to the starting information, which may lead to overestimation or underestimation (Epley & Gilovich, 2006).

For example, a prior study found that many US citizens used the benchmark values, 0%, 50%, and 100% for their estimates of risks associated with COVID-19 infection and vaccination (Yoon et al., 2022). Konold (1989) suggests that people who use the 'outcome approach' in their probabilistic reasoning focus on outcomes of single trials of events by interpreting 0% as meaning 'no', 50% as meaning 'I don't know', and 100% as meaning 'yes'. Yoon and colleagues (2022) used the outcome approach construct to hypothesize the citizens' meanings for those benchmark values. Our theoretical focus on citizens' meanings is inspired by Thompson's work on mathematical meaning (Thompson, 2015). We remained alert that two different people could have different meanings for the same percentage and used the outcome approach as a way to make sense of the different meanings participants might have.

Methods

We collected interview and survey data. Both asked South Korean citizens to quantify their risks associated with COVID-19 infection and vaccination and to discuss how they reason about the risks. First, we conducted a survey with a random sample of 50 South Korean adults on June 13, 2022 using a Korean survey company, Survey Top (https://www.surveytop.co.kr/)[1]. In our sample, there were 23 male and 27 female participants. The mean of participants' age was 41.34 years (SD = 14.77). As the level of highest education, 22 citizens reported a high school diploma and/or some college credits, and 28 citizens reported having a bachelor's degree or higher. Out of the 46 participants who received at least one dose of COVID-19 vaccines, 13 citizens were fully vaccinated for COVID-19 (two-doses of Pfizer of Moderna or a single dose of J&J vaccine), 31 citizens were fully vaccinated for COVID-19 with one booster shot, and two citizens had received two booster shots. Four citizens responded that they had never received a COVID-19 vaccine. Survey questions were developed in prior research (Yoon et al., 2022) and included: 1) If you were infected with COVID-19, what do you think your percent risk of hospitalization from COVID-19 if infected. Why? 2) If you were infected with COVID-19, how concerned would you be about getting hospitalized? 3) If you receive a COVID-19 vaccine in the future, what do you think your percent risks of a serious adverse reaction would be? Why? Other questions are also asked such as demographic information, their reasons for vaccination, and general probabilistic questions.

We also recruited three South Korean citizens for interviews. All participants were male, in their thirties, and held an undergraduate degree in non-mathematical fields. Both Chang-seob and Byung-soo (pseudonyms) were fully-vaccinated with a booster shot. Byung-soo was vaccine-hesitant; he received COVID-19 vaccines because of social pressure. Sun-kyu (pseudonym) had

1 The survey company provides information about the demographics of the panel and how to select a random sample from the panel (https://www.surveytop.co.kr/online-survey-panel).

not received any vaccines. Interviews were conducted through Zoom in Korean by the first author between June 19th, 2022 and July 4th, 2022. Each interview lasted approximately an hour and a half. During the interviews, the first author asked participants to quantify various risks associated with COVID-19 infection and vaccination, their opinions about COVID-19 vaccination, and to interpret meanings of particular percentages in various contexts. The first and third authors, who are South Korean, translated the US survey and interview protocol into Korean. We coded the data using a priori and emergent codes and conducted a thematic analysis (Braun & Clarke, 2006). While conducting our study and analyzing data, we were alert to the possibility that South Korean citizens would use benchmark values to reason about risk and that their meanings for a particular percentage might differ from experts' meanings.

Results

We found that participants' risk perceptions and reasonings were complex, but they commonly used benchmark values as a starting point for estimating their COVID-19 infection and vaccination risks. In both the survey and interviews, we observed that many participants used certain values, 0%, 1%, 10%, and 50%, as benchmark values. In order to answer the research question, we focus on how South Korean citizens quantify risks using benchmark percentages and make sense of the severity of those percentages.

Citizens' COVID-19 Infection and Vaccination Risk Estimates on Survey

In the survey data, we found noticeable clusters at 10% and 50% in citizens' estimates. In response to questions about risks related to both infection and vaccination, 10% was the most frequent estimate. When estimating their personal COVID-19 hospitalization risk if infected, 24% of citizens (12 of 50) estimated 10%. Further, 16% of citizens (8 of 50) estimated their risks of serious adverse reactions to COVID-19 vaccination as 10%. The question about adverse reactions clarified "An example of a serious adverse reaction is an allergic reaction requiring treatment in a hospital. Do not include your risk of common side effects such as fatigue." Another frequent estimate was 50%. For their COVID-19 hospitalization risk if infected and COVID-19 vaccination risk, 18% of citizens (9 of 50) and 12% of citizen (6 of 50) estimated 50%, respectively (Figure 1).

We also wanted to understand citizens' meanings for estimates of 0% because there is a small cluster at 0% (6 of 50) in the estimates of COVID-19 hospitalization risk if infected, and 0% is a value that appeared in our study of US citizens (Yoon et al., 2022).

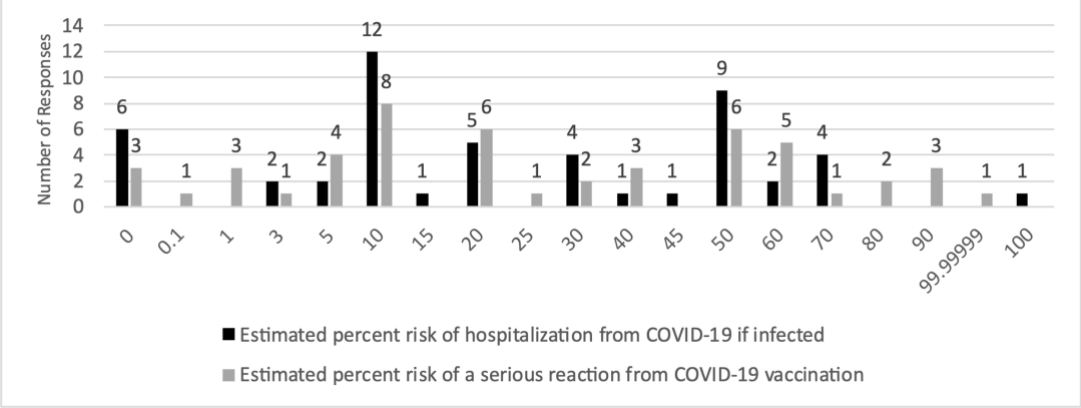

Figure 1. Citizens' estimated percent risk associated with COVID-19 infection and vaccination.

Use of Benchmarks in COVID-19 Infection and Vaccination Risk Estimates

Because 0%, 10%, and 50% were common estimates in the survey and interview data, we decided to focus on interview participants' meanings for these values and how they used them as benchmarks for estimation. Additionally, we discuss 1% as a benchmark value which emerged in our interview data, and we relate interview data with short fill in the blank responses on the survey.

50% as a Benchmark. During the interview, Byung-soo estimated his COVID-19 hospitalization risk if infected and unvaccinated as 50%. When asked how he quantified the 50%, Byung-soo said "I really don't know. I don't know how to estimate that risk as a probability. I have no reason for it". His response suggests his meaning of 50% is "I don't know" which may be explained by the outcome approach (Konold, 1989). Similarly, in the survey data, four of nine citizens who estimated their risk of COVID-19 hospitalization if infected as 50% and three of six citizens who estimated their risks of serious adverse reactions to COVID-19 vaccination as 50%, gave the reason for their estimate of 50% as "because I don't know". Thus, many citizens used 50% as a benchmark if they were unsure of their risk.

0% as a Benchmark. Chang-seob initially estimated his risk of dying from COVID-19 if infected and unvaccinated (in the case of the Omicron variant) as 0% since he thought that it would never happen to him. When asked to estimate his risk of dying from COVID-19 if infected and unvaccinated, he said: "I think my COVID-19 death risk from Omicron is 0% because I think I will not die if I were treated". Chang-seob used 0% as a benchmark to estimate his COVID-19 death risk if infected and unvaccinated given various treatments. Sun-kyu, who also thought that he would not die from COVID-19 if infected and unvaccinated, said "my risk would be convergent to 0%".

Similarly, in the survey, all six citizens who estimated their risk of hospitalization from COVID-19 if infected as 0% explained that they are unlikely to be hospitalized from COVID-19 if infected. An outcome approach explains that a benchmark of 0% means "No, it will not occur" (Konold, 1989). Therefore, 0% is associated with an event that is impossible or unlikely to occur.

10% as a Benchmark. Sun-kyu used a benchmark of 10% for estimating his risks associated with COVID-19 infection and vaccination. Sun-kyu estimated his risk of COVID-19 hospitalization if infected and unvaccinated and his risk of a serious adverse reaction from COVID-19 vaccination as more than 10%. On the other hand, he gave estimates less than 10% for his risk of COVID-19 hospitalization if infected and vaccinated (Table 1).

Table 1. Sun-kyu's estimates of risks associated with COVID-19 infection and vaccination.

Risk of		
COVID-19 Hospitalization, if infected and unvaccinated	COVID-19 Hospitalization, if infected and vaccinated	a serious adverse reaction to COVID-19 vaccine
10~20%	5~10%	30~40%

He transformed 10% into 1 out of 10. In this way, he interpreted 10% risk as "I don't think that 10% risk associated with COVID-19 infection is high. But, one or two out of 10 people is not too low to ignore. So, I would be concerned about it a little". In addition, he estimated his risk of serious adverse reactions from COVID-19 vaccination as 30~40%: "With a risk of 30%

related to vaccine side effects, I could be the one who had severe vaccine reactions, so I would much worry about it". Sun-kyu considered 30-40% as risky because it is more than one or two out of ten people, and so he used 10% as a benchmark and adjusted from a low risk of 10% to a higher risk of 30-40%.

In the survey, we found that all 12 citizens who estimated their COVID-19 hospitalization risk if infected as 10% tended to think that 10% is not very risky on a multiple choice follow up question. Of the 12 citizens, three responded that they were not concerned, five responded that they were slightly concerned, and four responded they were somewhat concerned about getting hospitalized if they were infected with COVID-19. Thus, participants from both the survey and interviews may use a benchmark as 10% to estimate a risk of an event that seem not very risky.

1% as a Benchmark. During the interviews, we observed 1% was used as a benchmark to estimate risk and participants adjusted the 1% upward or downward to reach their final estimates. We also found that participants thought 1% was a small risk and that risks with less than a 1% chance were unlikely to occur. Two interview participants thought COVID-19 risks less than or equal to 1% are not worth worrying about. For example, Chang-seob used 1% as a benchmark for all estimates of his risk associated with COVID-19 infection and vaccination (Table 2).

Table 2. Chang-seob's estimates of risks associated with COVID-19 infection and vaccination.

COVID-19 Risk of			
Hospitalization, if infected (unvaccinated)	Hospitalization, if infected (vaccinated)	Dying, if infected (vaccinated)	A serious adverse reaction to vaccine
1%	0.1%	0.001%	0.001~0.0001%

When the first author asked Change-seob to estimate his risk of hospitalization and dying from COVID-19 if infected and unvaccinated, he said:

> I estimate 1%, at most, that I would be hospitalized from COVID-19 if infected and unvaccinated. I think my risk of dying from COVID-19 if infected and unvaccinated would be from 0.01% to 0.1%. Assuming I am treated, I multiplied 0.01 to the 1% risk of hospitalization from COVID-19 and multiplied 0.1 to the 1% if not treated. Similarly, when vaccinated, I multiplied 0.1 to the 1% and got 0.1% risk of hospitalization from COVID-19 if infected. Also, I multiplied 0.1 to 0.01% risk of dying from COVID-19 if infected and unvaccinated and got 0.001% for my risk of dying from COVID-19 if infected and vaccinated.

Chang-seob started from 1% as his estimated risk of COVID-19 hospitalization risk if infected and unvaccinated. Then, he adjusted the 1% to 0.1% and 0.01% to estimate his risks associated with COVID-19 infection if infected and vaccinated. He thought every other risk in Table 2 was less likely than hospitalization if infected and unvaccinated. He adjusted his 1% estimate downward by multiplying 1% by 0.1, 0.01 and 0.001 to estimate other risks. Thus, Chang-seob used a benchmark of 1% for estimates of his risk associated with COVID-19 infection and vaccination. Additionally, he thought a 1% chance of hospitalization is not risky to him:

> I'm just splitting the risks less than 1%, so I feel like 0.1%, 0.01%, and 0.001% are all the same to me which are extremely low and 0.0001% is almost 0%. If a risk is less than 1%,

I think the probability is low no matter what the value is, because it means less than 1 out of 100 people.

Sun-kyu made a similar judgement about a 1% risk associated with COVID-19 infection and vaccination: "But if the chance has more zeros in the percentage such as 0.000…%, I would feel safe and comfortable with the risk". He interpreted risks of the form 0.000…% as "1 out of 1,000, 1 out of 10,000, and so on". Both Chang-seob and Sun-kyu used 1% or 1 out of 100 people and noted that if risks are less than 1%, it is meaningless to differentiate between them.

Discussion and Conclusion

From surveying and interviewing South Korean citizens about their COVID-19 risks, we found they used benchmark values of 0%, 1%, 10%, and 50%, and participants conveyed that 10% and 1% risk are not risky. Interview participants used and interpreted the benchmark values of 1% and 10% for their COVID-19 risk as 1 out of 100 people and 1 out of 10 people, respectively, for who would be at risk. This may have led participants to perceive risks less than 1% as small and negligible because they count the number of people out of 100 people, and 1 person is the smallest countable number from those 100 people. Compared to a sample size of 100, they perceived the occurrence of 1 out of 10 people as something that cannot be ignored but is slightly risky. Thus, reasoning with a frequency format using the number of people out of 10 or 100 may explain the use of benchmark 1% and 10% and why those risks were not perceived as risky.

In contrast, risks under 1% were more likely to be measured in a percentage format by a number of zeros in a decimal. When asked to transform 0.1% and 0.01% into a frequency format, the interview participants were able to correctly get 1 of 1,000 and 1 of 10,000. Nevertheless, they preferred to quantify risks less than 1% in a percentage format. Thus, the participants' use of denominators (100 and 10) may explain why they thought 1% was not risky, and the smallest risk value they would pay attention to because 0.1% means less than 1 person dies out of 100.

However, if the infection fatality rate of COVID-19 was 1%, and all 50 million South Korean citizens were infected, 500,000 people would die. Although the South Korean citizens in both our interviews and survey viewed risks near 1% as not too serious, it is clear that these risks are serious on a population scale. South Korean citizens' estimates of risk in our survey are problematic and worthy of attention in the international mathematics education community. Before vaccines were available, the infection fatality rate of COVID-19 was estimated to be about 0.68% (Meyerowitz-Katz & Merone, 2020). Although this is less than 1%, it was still significant enough to cause significant loss of life, overwhelm medical systems, and lower life expectancies. A 10% or even 1% infection hospitalization rate would be catastrophic from an epidemiological perspective.

Measuring small risks is hard. Small risks are represented in both frequencies and percentages. When thinking about the meaning of a percent in the COVID-19 context, it is important to think about that percent of a population of people. Moreover, it is important to understand the equivalent relationship in fractions and percents for risk perception, but many students as well as adults struggle with it (Sharp, 2002). These difficulties in understanding probabilistic information may cause problems in risk communication (Covello et al.,1986). Imagine if an epidemiologist tells us that a disease has a 5% infection fatality rate thinking that this will convey that the disease is extremely serious but what is actually conveyed to people is that they do not need to worry because it is less than their benchmark of 10%. As college instructors, it is important for us to ensure the graduates of our institutions are prepared to make sense of risks and develop more productive meanings for percent risks.

References

Bernstein, P. L. (1996). *Against the gods: The remarkable story of risk* (Vol. 383). John Wiley & Sons New York.

Botterill, L., & Mazur, N. (2004). Risk and risk perception: A literature review. *Kingstrom, ACT: Australian Government Rural Industries Research and Development Corporation*.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101.

Byerley, C. (2019). Calculus students' fraction and measure schemes and implications for teaching rate of change functions conceptually [Article]. *Journal of Mathematical Behavior*, *55*. https://doi.org/10.1016/j.jmathb.2019.03.001

CDC COVID-19 Response Team, & Food and Drug Administration (2021). Allergic reactions including anaphylaxis after receipt of the first dose of Pfizer-BioNTech COVID-19 vaccine - United States, December 14-23, 2020. MMWR. Morbidity and mortality weekly report, 70(2), 46–51. https://doi.org/10.15585/mmwr.mm7002e1

Covello, V. T., Slovic, P., & Von Winterfeldt, D. (1986). Risk communication: A review of the literature.

Covello, V. T., Winterfeldt, D. v., & Slovic, P. (1987). Communicating scientific information about health and environmental risks: Problems and opportunities from a social and behavioral perspective. In *Uncertainty in risk assessment, risk management, and decision making* (pp. 221-239). Springer.

Dieckmann, N. F., Slovic, P., & Peters, E. M. (2009). The use of narrative evidence and explicit likelihood by decisionmakers varying in numeracy. *Risk Analysis: An International Journal*, *29*(10), 1473-1488.

Douglas, M. (2013). *Risk and blame: Essays in cultural theory*. Routledge.

Epley, N., & Gilovich, T. (2006). The anchoring-and-adjustment heuristic: Why the adjustments are insufficient. *Psychological science*, *17*(4), 311-318.

Gigerenzer, G. (2011). THE ART OF RISK COMMUNICATION: What are natural frequencies? BMJ: British Medical Journal, 343(7828), 827.

Han, S. (2021, December 13). "접종 강요 아닙니까!" 식당·카페 '백신 패스' 의무화... 미접종자들 '분통' ["Isn't it forcing to get vaccinated!" Mandatory 'vaccine pass' at restaurants and cafes… Anger from non vaccinated people]. *Asia Economy*. https://www.asiae.co.kr/article/2021121219140313581

Hoffrage, U., Lindsey, S., Hertwig, R., & Gigerenzer, G. (2000). Communicating statistical information. In (Vol. 290, pp. 2261-2262): American Association for the Advancement of Science.

Konold, C. (1989). Informal conceptions of probability. *Cognition and instruction*, *6*(1), 59-98.

Korea Disease Control and Prevention Agency. (2022). *Coronavirus-19.* http://ncov.mohw.go.kr/

Krause, C. M., Di Martino, P., & Moschkovich, J. N. (2021). Tales from three countries: reflections during COVID-19 for mathematical education in the future. *Educational Studies in Mathematics*, *108*(1), 87-104.

Meyerowitz-Katz, G., & Merone, L. (2020). A systematic review and meta-analysis of published research data on COVID-19 infection fatality rates. International Journal of Infectious Diseases, 101, 138-148.

Mullis, I. V. S., Dossey, J. A., Owen, E., & Phillips, G. W. (1991). *The state of mathematics achievement : NAEP's 1990 assessment of the nation and the trial assessment of the states*. National Center for Education Statistics.
Peters, E. (2012). Beyond comprehension: The role of numeracy in judgments and decisions. *Current Directions in Psychological Science*, *21*(1), 31-35.
Peters, E., Västfjäll, D., Slovic, P., Mertz, C., Mazzocco, K., & Dickert, S. (2006). Numeracy and decision making. *Psychological science*, *17*(5), 407-413.
Purchase, I. F., & Slovic, P. (1999). Quantitative risk assessment breeds fear. *Human and Ecological Risk Assessment: An International Journal*, *5*(3), 445-453.
Raiffa, H. (1982). *Risk and decision making : perspectives and research*. National Academy Press.
Rothwell, J., & Witters, D. (2021). *Gallup*. https://news.gallup.com/opinion/gallup/354938/adults-estimates-covid-hospitalization-risk.aspx
Sharp, B. B. (2002). *Understanding relationships among fraction, decimal, and percent concepts*. California State University, Dominguez Hills.
Slovic, P. (1987). Perception of risk. *Science*, *236*(4799), 280-285.
Slovic, P., Monahan, J., & MacGregor, D. G. (2000). Violence risk assessment and risk communication: The effects of using actual cases, providing instruction, and employing probability versus frequency formats. *Law and human behavior*, *24*(3), 271-296.
Special Interest Group of the Mathematical Association of America Conference on Research in Undergraduate Mathematics Education. (2022). http://sigmaa.maa.org/rume
Stigler, J. W., & Hiebert, J. (2009). *The teaching gap: Best ideas from the world's teachers for improving education in the classroom*. Simon and Schuster.
Survey Top. (n.d.). https://www.surveytop.co.kr
Thompson, P. W. (2015). Researching mathematical meanings for teaching. In *Handbook of international research in mathematics education* (pp. 447-473). Routledge.
Tversky, A. (1974). Assessing uncertainty. *Journal of the Royal Statistical Society: Series B (Methodological)*, *36*(2), 148-159.
Wright, K. (2006). Barriers to accurate drug calculations. *Nursing standard*, *20*(28).
World Health Organization. (n.d.). Ten health issues who will tackle this year. World Health Organization. Retrieved February 14, 2022, from https://www.who.int/news-room/spotlight/ten-threats-to-global-health-in- 2019
World Health Organization (2020). Behavioural considerations for acceptance and uptake of COVID-19 vaccines: WHO technical advisory group on behavioural insights and sciences for health, meeting report, 15 October 2020.
Yoon, H., Gong, M., Byerley, C., Park, M. S., Horne, D., & Idrus, U. (2022). Modeling COVID-19 vaccine hesitancy using research on probabilistic thinking. In Lischka, A. E., Dyer, E. B., Jones, R. S., Lovett, J., Strayer, J., & Drown, S. (Eds.), Proceedings of the Forty-Fourth Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education(pp.849-858). Nashville, TN: Middle Tennessee University.