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# Understanding the Relationship Between Religiosity, Religious Affiliation, Prior Knowledge of Nanotechnology, and the Ethical Attitudes of Nanotechnology

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## Abstract

Nanotechnology has been a critical field of study through its integration of many appliances. With public trust conflicting with the acceptance of nanotechnology, researchers have established that certain variables - such as prior knowledge of nanotechnology, religion, and religiosity - play a significant role in shaping people's ethical perceptions of nanotechnology and, eventually, their public opinions. Therefore, this study focuses on finding and building the relationships between knowledge, religion, religiosity, and ethical concern of nanotechnology among teenagers in Granada Hills, California, to understand the influence of these variables on student perceptions of nanotechnology. A correlational study using quantitative data including a demographic survey, a 15-question Centrality of Religiosity Scale, prior knowledge evaluation, and an ethical concern section was administered to high school students from two schools in Granada Hills. Pearson product-moment correlations, ANOVA, and descriptive statistics were used to analyze the data. The results depicted that there was a negative relationship between knowledge and mean ethical concern, a negative relationship between knowledge and mean religiosity, a positive relationship between mean religiosity and mean ethical concern, and a positive correlation between age and mean knowledge of nanotechnology, all with weak coefficients. Ethical concerns were also explored, and students were found to be the most concerned about nanotechnology getting in the "wrong hands" and the loss of freedom and privacy. Additional research should be conducted on greater populations that consider different sociodemographic, affective, sociodemographic, or cognitive variables.

*Keywords: Nanotechnology, Ethical Concern, Public Trust, Religiosity, Religion, Knowledge*

## 1. Introduction

Throughout the recent decade, nanotechnology has made an increasingly relevant presence among society and many sectors of public well-being. Whether it is through medical applications, transportation, food, or even environmental conservation, the versatile nature of nanotechnology has been manipulated and integrated to improve many foundational sectors. According to physicist Richard Feynman, the scientific definition for nanotechnology is the application of atoms at the nanoscale across various fields including chemistry, biology, medicine, and engineering (NNI). With greater advancements, nanotechnology has the capability to improve the human condition through efficient disease prevention, sustainable practices, and water filtration for poverty-stricken communities.

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For instance, nanotechnology has significantly aided cancer treatments because of its increased "biocompatibility, reduced toxicity, more excellent stability, enhanced permeability and retention effect, and precise targeting" (Gavas et al., 2021). Therefore, there is no doubt that nanotechnology will be the future of science and be used to target global crises. However, despite the market value for nanotechnology rising to an astounding $76 billion, the lack of public trust among consumers has only hampered national acceptance of nanotechnology. Among the first polls conducted in 2004, the National Science Foundation found that 49% of the respondents had "heard nothing at all" about nanotechnology, while many believed preconceived notions about its practical use, moralities, and accessibilities (Institute of Medicine (US) Food Forum). Four years later, a similar poll was conducted, only to find that an increasingly large portion of people still had limited knowledge about nanotechnology and failed to give their thoughts about its risks and benefits. Since Americans have yet to gain public awareness of nanotechnology, commercialization of modernized technologies has progressed slower (Peter D. Hart Research, Inc. 2008). Julia Moore, director of the Wilson Center, argued that misinformation or a lack of knowledge correlates with unguided public approval for nanotechnology, stating that "public opinion is really up for grabs when it comes to nanotechnology" (Institute of Medicine (US) Food Forum). Among the many other reasons for distrusting nanotechnology, religiosity, defined as the "behavior and beliefs associated with organized religion" is also becoming an important variable, as previous studies have demonstrated that being more religious meant having less trust in science (Good et al., 2011, pg 538). According to a survey incorporating 1,015 participants done by the Center for Nanotechnology, Americans had shown a strong negative correlation between religiosity and the acceptance of nanotechnology (Scheufele et al. 2009). Finally, acknowledging the ethical dilemmas that people may have about nanotechnologies, such as its military uses, environmental consequences, and medical complications, may allow the concerns of consumers to be heard to prevent widespread backlash or skepticism (Macoubrie, 2006). Therefore, this paper strives to explore how religious alliances, prior knowledge, and ethical issues may correlate with the limited social approval of nanotechnologies among consumers.

### 1.1 Theology of Religion and Religiosity Within Nanotechnology

Religion has continually had a lasting impact on people's opinions regarding technology and its vast outreach. Franz Foltz, Assistant Professor at Rochester Institute of Technology, and Fredrich Foltz specifically examined the Christian response to nanotechnology by describing the four naive views of religion. One of the views they mentioned was that certain morals such as human dignity or social justice might be amplified with nanotechnology. For instance, biotechnology used to manipulate human characteristics is "not preserving human dignity" since the Roman Church believes this is playing the hands of God (F. Foltz and FR. Foltz, 2006). Similarly, Kotze, Manitza (2018) attempted to look at the bioethical issues that genetic engineering and robotics raised from a theological perspective. Transhumanism, a word only popularized in the 1950s, meaning the enhancement of human beings and what it means to be human has posed conflicts for religious individuals' perceptions of nanotechnology. The World Transhumanist Association released a statement stating that on one hand, bioelectronics enables humans to perform at a high- functioning level, while on the other hand, the human body is almost "dematerialized" into "a partially artificial being- a cyborg" (Kotze, 2018, pg. 1). She also discussed how disapproval for transhumanism could reflect onto people's public trust, public opinion, and medical science views on nanotechnology.

Other than religious affiliation, religiosity has already proven to be a determining factor in people's disposition for nanotechnology (Good et al., 2011, pg 538). National data was used to examine how people utilized science media, knowledge about nanotechnology, and predispositions, such as the strength of religious beliefs, to form their attitudes about nanotechnology. A national telephone survey

of 706 respondents found that there seemed to be a significant negative relationship between the strength of religious beliefs and support for funding (Brossard et al., 2009). Agreeing with Franz Foltz and Fredrich Foltz, people with a strong connection to religion had been opposed to funding nanotechnology because of their belief that it had human-altering properties (Brossard et al., 2009). While understanding ethical concerns, Scheufele et al. (2009) surveyed more than 1,015 Americans and 29,193 Europeans and found that there was a negative correlation between religiosity and the morality of technology. They identified that strong religiosity often led to citizens perceiving nanotechnology as ethically wrong. Among European countries, there were more positive outlooks on nanotechnology with a weaker connection to religiosity, which may be explained by the secularized education system of many European nations (Scheufele et al. 2009). Therefore, being highly religious, or having a strong connection with religion and participating in religious practices, has been shown to have a negative correlation with the general ethical perceptions of nanotechnology.

However, most research studies took an approach looking at older populations, ranging from 25–60-year-olds, with less focus on the youth. According to data released by the PEW Research Center, about 50% of teens responded that they either share the same religious values as their parents or differ slightly. With the recent uprise in the youth identifying as Atheist or Agnostic, 66% of teens who do religious practices with their family say they do so partly because their parents want them to (Diamant and Sciupac, 2020). Since a greater societal role is being played by teens, many ideologies about nanotechnology, passed down by parents, may affect the public opinions that teens hold on consumer products. Additionally, identifying the correlation that younger generations have with religion and religiosity may be the key to understanding their opinions about the uses of nanotechnology in order to better adapt to their concerns.

### 1.2 Knowledge of Nanotechnology

Prior knowledge of nanotechnology also has the potential to influence public support and funding for them. In the early 2000s, there was an influx of science-fiction culture and optimism for nanotechnology, even though there was a lack of knowledge of what nanotechnology was. Although the percentage of people who have “heard nothing at all” about nanotechnology decreased from 2006 to 2010, more than half of the population has limited knowledge of nanotechnology (Binder, 2013). Dominique Brossard and her peers at the University of Wisconsin-Madison identified that religiosity is also connected with knowledge, in that highly religious individuals were shown to have lower knowledge of nanotechnology and therefore, had lower reasons to support it (Brossard et al., 2009). Their misconceived views could have not only been reinforced by their strong religious connection but could also have been passed down to their children. Jane Macoubrie’s study (2006) utilized a quasi-experimental group and established that public policies and concerns about nanotechnology must be addressed by people who are knowledgeable about nanotechnology for it to be properly evaluated.

In the study presented by Gardner, Grant et al. (2010), the “knowledge deficit model” claims that increased knowledge about a complex topic “promotes more rational formation of attitudes” (Gardner et al., 2010). Hence, his research question of understanding the risk perceptions of nanotechnology came from questioning undergraduate students in the engineering fields. Gardner explains that since undergraduate courses often are the first contact that students have with nanotechnology discourse, this is where their attitudes start forming about the practices of nanotechnology. Therefore, undergraduates exposed to nanoscale science were chosen for his study because of their greater education in nanotechnology. Both studies reflect that through greater education and knowledge of nanotechnology, people may be able to bridge the gap between skepticism and national acceptance of its integration. Furthermore, to generate effective dialogue over the values, visions, and societal implications of nanotechnology, an effective ‘nanotechnology engagement project’ should be developed. One that uses a two-way dialogue system between scientists and the public will impact regulations of nanotechnology (Pidgeon

et al., 2011).

### 1.3 Theoretical Framework

Since public trust remains a relevant issue in gaining approval for technologies, such as nanotechnology, it is vital to discuss how to address the concerns of laypeople (non-experts). According to researcher Trond Am, from the Norwegian University of Science and Technology, there are two key reasons for the lack of concern that people have expressed against technological advancements: 1) prior technological controversies that have been poorly handled by the government and 2) the ambiguity within scientific advances that run ahead of public awareness and control (Am, 2011). Therefore, tools such as the Nanotechnology-Perception Attitude Acceptance Framework (Nano-PAAF), developed by Dr. Achinitya Bezbaruah, and Dr. Rajesh Pillai (2017), help build a systemic understanding of the phenomenon by addressing how certain consumer behaviors impact public trust and attitudes toward nanotechnology. The framework proposed that people's perceptions of nanotechnology are influenced by cognitive, affective, socio- cultural, and sociodemographic factors. Among the cognitive factors, Pillai and Bezbaruah reinforced the idea that knowledge about nanotechnology has been related to greater support for it and a positive attitude toward science (Scheufele and Lewenstein, 2005). Compared to experts, laypeople perceive greater risks and lower support for new technologies, which is why it may be useful to identify their prior knowledge to get a better indicator of where their attitudes lie. Additionally, sociocultural factors such as a strong religious standing was correlated with lower levels of trust within nanotechnology. Nano-PAAF suggested that "non-experts are more likely to use religious beliefs as a heuristic cue to assess nanotechnology risks as compared to experts" even when factors like trust, knowledge, and media exposure are controlled (Pillai and Bezbaruah, 2017, pg. 7). Overall, identifying the factors expressed in the Nano-PAAF can be a good indicator of the ethical concerns that consumers have toward nanotechnology based on their perceived risks and benefits. Eventually, these concerns can be efficiently tackled through regulations and public policies. Hence, Nano-PAAF is used to observe how prior knowledge and religiosity may shape the ethical attitudes consumers have toward nanotechnology.

### 1.4 Research Question

After analyzing past research related to the ethical perceptions of nanotechnology and the variables suggested before, there has been a lack of research correlating all four of the variables: religious affiliation, religiosity, prior knowledge, and ethical perceptions. More specifically, previous studies did not take any approach to understand the role that these variables played among teenagers. Therefore, this research paper will try to bridge this gap through an exploratory study of the relationship between these variables.

In addition, the Granada Hills region in California was analyzed as a starting point to guide future research on greater regions in the US. Many schools in Granada Hills are diverse with approximately 75% minority enrollment and a range of students from various socioeconomic backgrounds. Therefore, Granada Hills was chosen as an ideal location to gain perspectives from students of different upbringings and backgrounds, leading to the research question: what is the relationship between religious affiliation, religiosity, prior knowledge of nanotechnology, and the ethical concerns that high school students in the Granada Hills region have on nanotechnology?

Exploring this research question will allow public policymakers and nanotechnology innovators to cater to and address the ethical concerns that teenagers may have, considering their varying religious and socio-cultural backgrounds. Moreover, scientists can gain a deeper insight into the vulnerabilities of public trust through the lens of teenagers, who will eventually gain control over the industry.

## 2. Methods

This study used a quantitative survey to explore the correlation between religious affiliation, religiosity, prior knowledge of nanotechnology, and the ethical concerns that students have. This method was used to not only observe the relationships

between the variables but to do a correlational analysis of the various religions and ethical concerns using quantitative data.

2.1 Population

Data was collected from high schoolers in grades 9 -12 mainly because prior data concerning ethical attitudes toward nanotechnology failed to consider the perceptions of teens. Regardless, the teenager perspective is beneficial since they will soon serve as leading innovators and regulators of new technology, including nanotechnology. Chris Toumey, a researcher from the University of South Carolina, expressed how public reactions to nanotechnology must come from both scientific experts and regular citizens, specifically teens, and their perspectives (2004). Two major high schools in the Granada Hills region, referred to as School 1 and School 2, were analyzed. Both samples have the greatest student population compared to other high schools in the region and incorporate students from various religions: Christians (under the Protestant, Catholic, and Orthodox sectors), Atheists, Agnostics, Muslims, Hindus, and Jews. Granada Hills, California, was chosen because of its diverse religious population and progressive push in STEM curriculum (Patten and Newhart, 2018, pg. 52). Studying this population allowed the gap within my research question to be addressed, by analyzing whether the correlation between knowledge, religiosity, religion, and ethical concerns among teens are similar to the data collected from adults or whether there are overwhelming differences that require a different approach. Since it has been observed that teens are slowly becoming "disconnected" from religion and loosely following their guardians, it was crucial to observe whether religion and religiosity remained principal factors in determining attitudes toward nanotechnology as Nano-PAAF had suggested, or if there was a need to evolve the theory based on the newer generations (Good et al. 2011).

2.2 Instrument

The selected instrument was a survey sent through a Google Form that had 4 major sections which correlated with the points of interest. Primarily, there was a demographic questionnaire that asked the participant's name, grade level, age, school, race, and religious group, which also included an open-ended portion if they needed to elaborate on their current religious beliefs. This section was essential in recognizing other variables outside of my research scope that could influence the variables. The next section included a replica of the 15-question Centrality of Religiosity Scale (CRS) which is used to measure how religious a person is based on five core dimensions of religiosity: public practice, private practice, religious experience, ideology, and religious intelligence (S. Huber and O. Huber, 2012). The scale has been used across 25 different countries and has even been validated to support cross- cultural barriers and non-Abrahamic religions. Each item is scored on a scale of 1 to 5 and then the sum score is divided by the number of scored scale items. If the resulting number is between 1.0 to 2.0, they are not religious, 2.1 to 3.9 means they are religious, and 4.0 to 5.0 means that they are highly religious (S. Huber and O. Huber, 2012).

The following section was a simple Likert Scale adapted from Joubert et al. and their study on the current levels of knowledge and attitudes toward nanotechnology among the Austrian population. It asked, "To what extent do you feel informed about nanotechnology?" with scores ranging from 1 (I don't know anything about nanotechnology) to 4 (I am well versed in nanotechnology) (2020). Finally, the last section started with a short information page describing nanotechnology and its application to provide background information to the respondents before proceeding. That page included information quoted directly from the National Nanotechnology Initiative, Stephen J Florczyk and Subrata Saha's research paper, "Ethical issues in Nanotechnology," and "Applications of Nanotechnology in Daily Life" by Mahmoud Nasrollahzadeh et al. Jane Macoubrie, adjunct Professor at the University of Southern California, did a similar study where participants were given information cards about nanotechnology, then told to formulate potential ethical concerns that concerned them (Macoubrie, 2006). In the same manner, a Likert scale was created for each of those ethical concerns found in her study and asked the

respondents to rate them on a scale of 1 (not at all concerning) to 5 (very concerning). It was not left as an open- ended question because a limitation in my pilot study was that many students could not think of ethical concerns from the top of their heads.

2.3 Recruiting Method

To select students to take the survey, a systematic sampling method was utilized by contacting every 5th teacher on the school's faculty page to distribute the instrument to their classes. To reduce bias, teachers from every subject were chosen and there was no preference for male or female teachers (Patten and Newhart, 2018). Teachers were also listed alphabetically by each subject, however, only those teaching physical education or ESL were not contacted due to the inaccessibility of the instrument adapting to their learning environment. The trends and data were analyzed from all the students who participated in the survey in order to generalize the teens in Granada Hills, excluding those who fell into the category of minority religions (Patten and Newhart, 2018). Probabilistic sampling was utilized to collect a representative sample and compare the religious differences in the sample rather than selecting specific members of each religious identity.

2.4 Data Collection

After sending out the survey to 32 teachers, I received confirmation that those teachers had posted the link to their main platform for their students to take, by choice. Google Forms was used to distribute the survey because it was user-friendly, did not support duplicate answers, could automatically be linked to Google Sheets, and was the most accessible to teens.

To ensure no possible ethical concerns, samples of convenience were not used. Instead, a diverse population including students from regular classes to AP-level classes who would have various levels of knowledge about nanotechnology was examined (Patten and Newhart, 2018). All the questions that came from previous scales were validated while the personal questions were approved by the International Review Board. In addition, before taking the survey, participants were given a consent form, informing them of what their data was going to be used for, the type of questions asked, and how long the form would take, giving them the option to opt-out anytime.

## 3. Results

To test the relationships with the prior variables, I made a few adjustments to the sample size and collected demographic data as depicted in Table 1. The Jewish and Mormon religious groups had not reached a significant number of responses, so they were not utilized when doing any statistical tests.

Table 1: Descriptive statistics of the demographics of respondents

| | **Frequency (n)** | **Mean ($\bar{x}$)** | **Standard Deviation (σ)** |
|---|---|---|---|
| Total Respondents | 162 | | |
| **Age** | **-** | **15.8** | **±0.99** |
| 14 | 14 | - | - |
| 15 | 40 | - | - |
| 16 | 63 | - | - |
| 17 | 39 | - | - |
| 18 | 3 | - | - |
| 19 | 1 | - | - |
| Mean Religiosity | - | 2.93 | ±1.02 |
| Mean Prior Knowledge | - | 1.72 | ±0.71 |
| **Race** | | | |
| White | 46 | - | - |
| Black/African American | 14 | - | - |
| Native American and Alaska Native | 2 | - | - |
| Asian | 64 | - | - |
| Native Hawaiian and Other Pacific Islander | 7 | - | - |
| Hispanic | 48 | - | - |
| Other | 17 | - | - |
| **Religion** | | | |
| Agnostic | 18 | - | - |
| Atheist | 28 | - | - |
| Catholic | 60 | - | - |
| Jewish | 2 | - | - |
| Mormon | 2 | - | - |
| Muslim | 7 | - | - |

| | | | |
|---|---|---|---|
| Non-Abrahamic | 8 | - | - |
| Orthodox Christian | 19 | - | - |
| Protestant Christian | 15 | - | - |

Based on the demographic data, most students who completed the survey were roughly between the ages of 15 and 16, or 10th and 11th graders. The religious groups that were used in the data analysis process were Agnostic, Atheist, Catholic Christian, Muslim, Non-Abrahamic (including Hinduism and Buddhism), Orthodox Christian, and Protestant Christian, which is representative of the Granada Hills religious breakdown (Loksata, 2012)

3.1 Overall Ethical Concern

Table 2. Descriptive statistics of the level of concern among the following ethical issues in nanotechnology

| | **Mean Ethical Concern** | **Long-Term Health** | **Military Uses** | **Environmental Footprint** | **Social Footprint** | **Lost Freedoms** |
|---|---|---|---|---|---|---|
| Response Number | 161 | 161 | 161 | 161 | 161 | 161 |
| Mode | 3.000 | 3.000 | 4.000 | 4.000 | 3.000 | 5.000 |
| Median | 3.636 | 3.000 | 4.000 | 3.000 | 3.000 | 4.000 |
| Mean | 3.501 | 3.068 | 3.553 | 3.205 | 2.969 | 3.845 |
| Std. Deviation | 0.730 | 1.146 | 1.204 | 1.256 | 1.075 | 1.132 |

| | **Lack of Regulation** | **Losing Funding** | **Effects on Nature** | **Getting in "Wrong Hands"** | **Public Trust** | **Responsibly Researching** |
|---|---|---|---|---|---|---|
| Response Number | 161 | 161 | 161 | 161 | 161 | 161 |
| Mode | 3.000 | 3.000 | 4.000 | 5.000 | 3.000 | 3.000 |
| Median | 4.000 | 3.000 | 4.000 | 5.000 | 3.000 | 3.000 |
| Mean | 3.702 | 3.298 | 3.665 | 4.242 | 3.534 | 3.429 |
| Std. Deviation | 1.117 | 1.106 | 1.199 | 0.980 | 1.025 | 1.192 |

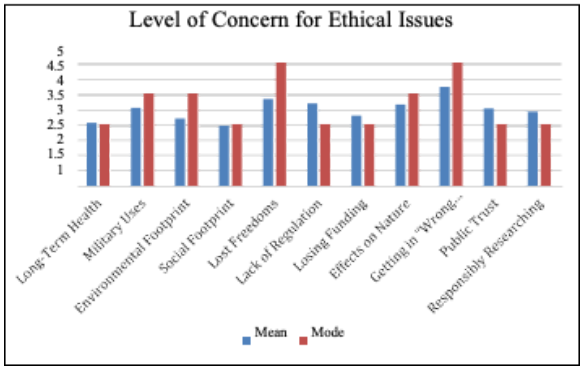


Figure 1. Bar graph depicting the mean and mode for each ethical concern on a scale of 1 (not at all concerning) to 5 (very concerning).

When analyzing the overall ethical concerns that the students had for nanotechnology, the following categories were used: long-term health concerns, military uses, environmental footprint, social footprint, loss of freedoms and privacy, lack of regulation, losing funding for other priorities, effect on nature, getting in the "wrong hands," public trust, and responsibly researching, adapted from Joubert et al., 2020 and the ethical concerns she collected from her study of nanotechnology. Among the concerns illustrated in Table 2 and illustrated in Figure 1, students were most concerned about nanotechnology getting into the "wrong hands" and the loss of freedoms and privacy that may develop from using nanotechnology. Overall, students seemed to have a neutral understanding of each concern with the lowest concern being the social footprint of nanotechnology, or the social implications.

A Pearson product-moment correlation coefficient was also calculated to see the relationships between each ethical concern. As shown in Table 3, most of

the concerns had shown a statistically significant positive correlation with each other, with the strongest correlations being environmental footprint vs. long-term health ($p < 0.001$, $r = 0.488$), environmental footprint vs. effects on nature ($p < 0.001$, $r = 0.580$), loss of freedoms vs. lack of regulation ($p < 0.001$, $r = 0.571$), getting in the "wrong hands" vs. public trust ($p < 0.001$, $r = 0.517$), responsibly researching vs. long-term health ($p < 0.001$, $r = 0.525$), and responsibly researching vs. public trust ($p < 0.001$, $r = 0.498$). Within each of these relationships, the data was significant since the p-value was less than 0.001, and one variable seemed to be strongly interconnected with another. For example, the more concerned students felt about the environmental footprint of nanotechnology, the more concerned they also felt about its long-term health effects. Therefore, many of the ethical concerns were strongly positively associated.

Table 3. Pearson's correlation of all the ethical concerns

| Pearson's Correlations | Pearson's r | p |
|---|---|---|
| Environmental Footprint - Loss of Freedoms | 0.203* | 0.011 |
| Environmental Footprint - Lack of Regulation | 0.158* | 0.047 |
| Environmental Footprint - Losing Funding | 0.207** | 0.009 |
| Environmental Footprint - Getting in Hands" | 0.277** | <.001 |
| Environmental Footprint - Responsibly Researching | 0.483*** | <.001 |
| Environmental Footprint - Long-Term Health | 0.488*** | <.001 |
| Environmental Footprint - Military Uses | 0.312*** | <.001 |
| Environmental Footprint - Social Footprint | 0.414*** | <.001 |
| Environmental Footprint - Effects on Nature | 0.580*** | <.001 |
| Environmental Footprint - Public Trust | 0.211** | 0.008 |
| Loss of Freedoms - Lack of Regulation | 0.571*** | <.001 |
| Loss of Freedoms - Losing Funding | 0.392*** | <.001 |
| Loss of Freedoms - Getting in "Wrong Hands" | 0.450*** | <.001 |
| Loss of Freedoms - Responsibly Researching | 0.366*** | <.001 |
| Loss of Freedoms - Long-Term Health | 0.386*** | <.001 |
| Loss of Freedoms - Military Uses | 0.247** | 0.002 |
| Loss of Freedoms - Social Footprint | 0.278*** | <.001 |
| Loss of Freedoms - Effects on Nature | 0.418*** | <.001 |
| Loss of Freedoms - Public Trust | 0.377*** | <.001 |
| Lack of Regulation - Losing Funding | 0.439*** | <.001 |
| Lack of Regulation - Getting in "Wrong Hands" | 0.477*** | <.001 |
| Lack of Regulation - Responsibly Researching | 0.345*** | <.001 |
| Lack of Regulation - Long-Term Health | 0.336*** | <.001 |
| Lack of Regulation - Military Uses | 0.298*** | <.001 |
| Lack of Regulation - Social Footprint | 0.332*** | <.001 |
| Lack of Regulation - Effects on Nature | 0.344*** | <.001 |
| Lack of Regulation - Public Trust | 0.470*** | <.001 |
| Losing Funding - Getting in "Wrong Hands" | 0.440*** | <.001 |
| Losing Funding - Responsibly Researching | 0.407*** | <.001 |
| Losing Funding - Long-Term Health | 0.305*** | <.001 |
| Losing Funding - Military Uses | 0.121 | 0.130 |
| Losing Funding - Social Footprint | 0.252** | 0.001 |
| Losing Funding - Effects on Nature | 0.384*** | <.001 |
| Losing Funding - Public Trust | 0.388*** | <.001 |
| Getting in "Wrong Hands" - Responsibly Researching | 0.461*** | <.001 |
| Getting in "Wrong Hands" - Long-Term Health | 0.355*** | <.001 |
| Getting in "Wrong Hands" - Military Uses | 0.348*** | <.001 |
| Getting in "Wrong Hands" - Social Footprint | 0.298*** | <.001 |
| Getting in "Wrong Hands" - Effects on Nature | 0.436*** | <.001 |
| Getting in "Wrong Hands" - Public Trust | 0.517*** | <.001 |
| Responsibly Researching - Long-Term Health | 0.525*** | <.001 |

| | | |
|---|---|---|
| Responsibly Researching - Military Uses | 0.196* | 0.014 |
| Responsibly Researching - Social Footprint | 0.403*** | <.001 |
| Responsibly Researching - Effects on Nature | 0.450*** | <.001 |
| Responsibly Researching - Public Trust | 0.498** | <.001 |
| Long-Term Health - Military Uses | 0.228** | 0.004 |
| Long-Term Health - Social Footprint | 0.328*** | <.001 |
| Long-Term Health - Effects on Nature | 0.420*** | <.001 |

*p < 0.05, **p < 0.01, ***p < 0.001

3.2 Religion vs. Religiosity

ANOVA was used to test the statistical significance between the mean religiosity scores of each religion. The test assumptions were checked, but Levene's test was significant (p = 0.001) since the sample size for each religion varied. Therefore, the null hypothesis that each religion had statistically insignificant religiosity variances was rejected. Normality was checked with a Q-Q plot and no deviations were noticed, which means that the data was normally distributed (Table 4 and 5).

There was a significant difference among the 7 religions studied and their religiosity scores (p < 0.001). Since the p-value was < 0.001, there was stronger evidence for the difference in means or that the data was statistically significant. Post hoc testing revealed significant differences between the religiosity scores from the Agnostic (Mean = 2.2, SD = 0.44), Atheist (Mean = 1.6, SD = 0.53), and Non-Abrahamic (Mean = 2.5, SD = 0.59) religions compared to Catholic (Mean = 3.3, SD= 0.73), Muslim (Mean = 3.8, SD = 0.82), Orthodox Christian (Mean = 3.3, SD = 0.96), and Protestant Christian (Mean = 4.0, SD = 0.66) (Table 6). The data showed that there was a clear difference in religiosity scores among the religions as lower means depicted lower religiosity while higher scores meant the opposite (Table 7). Atheism was shown to be the least religious, while Protestant Christians were shown to be the most devoted to practicing religion including worship and personal prayer.

Table 4. ANOVA results measuring mean religiosity among religious groups

| Cases | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Religious Group | 91.747 | 6 | 15.291 | 31.906 | <.001 |
| Residuals | 71.888 | 150 | 0.479 | | |

Table 5. Assumption check using Levene's Test for Equality of Variances

| F | df1 | df2 | p |
|---|---|---|---|
| 3.981 | 6.000 | 150.000 | 0.001 |

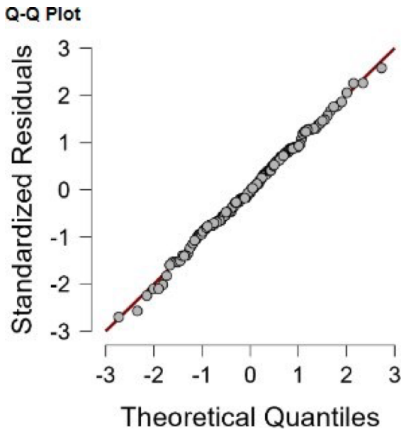


Figure 2. Q-Q plot is used to show that data points are normally distributed but are not equally varied through Levene's test for religiosity scores.

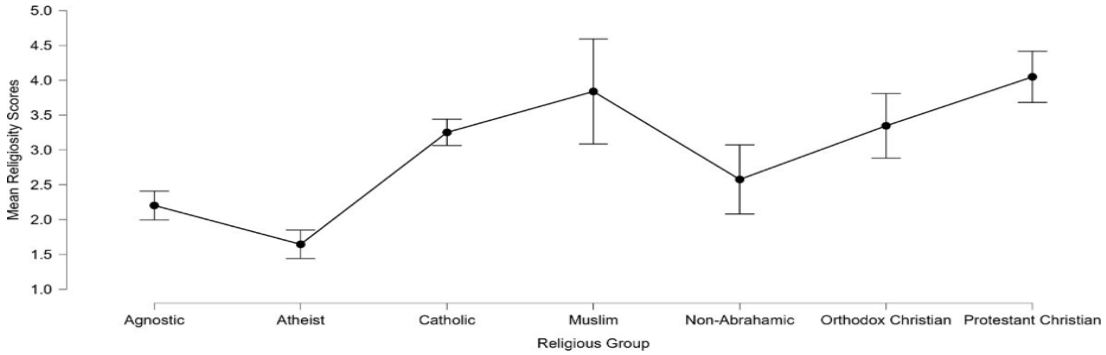


Figure 3. Descriptive plot showing the difference in religiosity scores among religious groups through ANOVA.

Table 6. Post Hoc comparisons among religious groups

| | | | 95% CI for Mean Difference | | | | |
|---|---|---|---|---|---|---|---|
| | | **Mean Difference** | **Lower** | **Upper** | **SE** | **t** | **$P_{tukey}$** |
| **Agnostic** | Atheist | 0.557 | -0.048 | 1.163 | 0.203 | 2.750 | 0.093 |
| | Catholic | -1.049 | -1.583 | -0.515 | 0.179 | -5.858 | <.001 |
| | Muslim | -1.636 | -2.544 | -0.727 | 0.304 | -5.380 | <.001 |
| | (Non-Abrahamic) | -0.373 | -1.239 | 0.492 | 0.290 | -1.289 | 0.856 |
| | Orthodox Christian | -1.143 | -1.806 | -0.480 | 0.222 | -5.153 | <.001 |
| | Protestant Christian | -1.846 | -2.552 | -1.139 | 0.236 | -7.805 | <.001 |
| **Atheist** | Catholic | -1.606 | -2.080 | -1.133 | 0.158 | -10.137 | <.001 |
| | Muslim | -2.193 | -3.067 | -1.319 | 0.293 | -7.496 | <.001 |
| | (Non-Abrahamic) | -0.931 | -1.760 | -0.101 | 0.278 | -3.353 | 0.017 |
| | Orthodox Christian | -1.700 | -2.315 | -1.085 | 0.206 | -8.262 | <.001 |
| | Protestant Christian | -2.403 | -3.065 | -1.741 | 0.222 | -10.848 | <.001 |
| **Catholic** | Muslim | -0.587 | -1.413 | 0.240 | 0.276 | -2.122 | 0.345 |
| | (Non-Abrahamic) | 0.676 | -0.103 | 1.454 | 0.261 | 2.593 | 0.136 |
| | Orthodox Christian | -0.094 | -0.639 | 0.451 | 0.182 | -0.516 | 0.999 |
| | Protestant Christian | -0.797 | -1.394 | -0.200 | 0.200 | -3.987 | 0.002 |
| **Muslim** | (Non-Abrahamic) | 1.262 | 0.191 | 2.333 | 0.358 | 3.523 | 0.010 |
| | Orthodox Christian | 0.493 | -0.422 | 1.408 | 0.306 | 1.610 | 0.676 |
| | Protestant Christian | -0.210 | -1.157 | 0.737 | 0.317 | -0.663 | 0.994 |
| **(Non-Abrahamic)** | Orthodox Christian | -0.770 | -1.642 | 0.102 | 0.292 | -2.637 | 0.122 |
| | Protestant Christian | -1.472 | -2.378 | -0.567 | 0.303 | -4.858 | <.001 |
| Orthodox **Christian** | Protestant Christian | -0.703 | -1.418 | 0.012 | 0.239 | -2.940 | 0.057 |

*P-value and confidence intervals adjusted for comparing a family of 7 estimates (confidence intervals corrected using the tukey method).

Table 7. Descriptive statistics of mean religiosity scores

| Religious Group | Mean | SD | N |
|---|---|---|---|
| Agnostic | 2.203 | 0.441 | 20 |
| Atheist | 1.646 | 0.528 | 28 |
| Catholic | 3.252 | 0.730 | 60 |
| Muslim | 3.839 | 0.815 | 7 |
| Non-Abrahamic | 2.579 | 0.594 | 8 |
| Orthodox Christian | 3.346 | 0.961 | 19 |
| Protestant Christian | 4.049 | 0.664 | 15 |

3.1 Religion vs. Prior Knowledge

To test the difference in prior knowledge among different religious groups, one-way ANOVA was used again. The test assumptions were checked, and Levene's test was non-significant (p = 0.288), meaning that there was not enough variance in the data to account for the difference in means (Table 8).

However, there seemed to be no significant difference among the religions since the p- value = 0.965 and there was a low F-value = 0.234 indicating that there was not much variation in the actual samples (Table 10). According to the descriptive plot in Figure 4, prior knowledge of nanotechnology did not differ among religious groups, as each had a high standard deviation including the seemingly religious ones.

Table 8. Levene's Test showing minimal variance in data for knowledge in different religious groups

| F | df1 | df2 | p |
|---|---|---|---|
| 1.242 | 6.000 | 150.000 | 0.288 |

Table 9. ANOVA results measuring mean knowledge scores among religious groups

| Cases | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Religious Group | 0.743 | 6 | 0.124 | 0.234 | 0.965 |
| Residuals | 79.359 | 150 | 0.529 | | |

Table 10. Descriptive statistics of respondents' knowledge of nanotechnology

| Religious Group | Mean | SD | N |
|---|---|---|---|
| Agnostic | 1.600 | 0.821 | 20 |
| Atheist | 1.786 | 0.738 | 28 |
| Catholic | 1.733 | 0.756 | 60 |
| Muslim | 1.857 | 0.378 | 7 |
| Non-Abrahamic | 1.750 | 0.707 | 8 |
| Orthodox Christian | 1.632 | 0.597 | 19 |
| Protestant Christian | 1.667 | 0.724 | 15 |

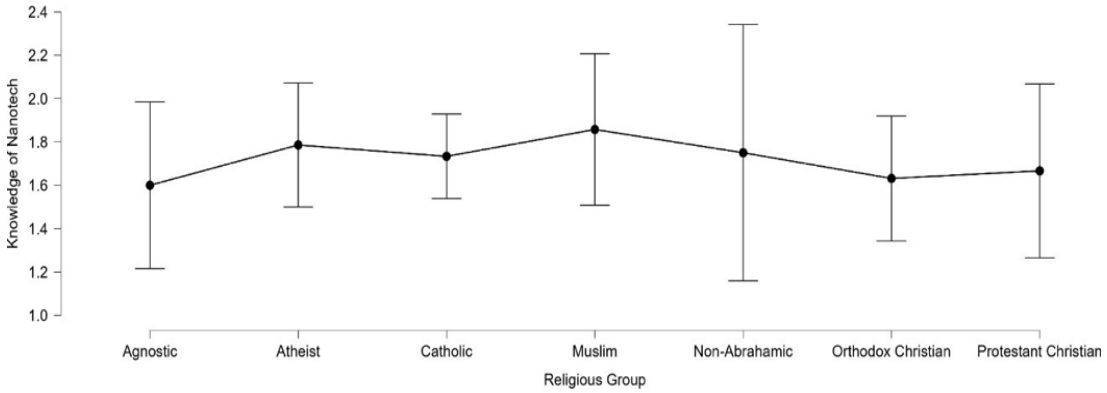


Figure 4. The graph depicts the comparisons of mean knowledge scores across the given religions.

### 3.1 Correlation Between Knowledge of Nanotechnology, Religiosity, and Mean Ethical Concern

To examine the relationship between the following variables, a Pearson product-moment correlation was conducted. This regression test measures the strength of a linear relationship between two variables and uses a coefficient from -1 to 1, with -1 being a strong negative linear correlation and +1 being a strong positive correlation. Among all the variables, there was a statistically significant relationship between knowledge of nanotechnology and mean ethical concern ($p < 0.05$) and a negative association between the two ($r = -0.185$). The findings suggest that a 1-point increase in knowledge of nanotechnology meant a 0.185-point decrease in overall ethical concern, or that more knowledge led to less concern for the usage of nanotechnology. Since the r-value was miniscule, there was only a slight correlation between the two variables.

The relationship between knowledge of nanotechnology and religiosity scores had a p-value = 0.26 and Pearson's r-value = -0.089 indicating that even though the data was not as significant, there was a negative correlation between the two meaning that a 1-point increase in the knowledge of nanotechnology had been linked to a 0.089-point decrease in religiosity. On the other hand, religiosity and the mean ethical concern were positively correlated with a p-value = 0.050 and Pearson's r-value = 0.157, showing that a 1-point increase in religiosity was linked to a 0.157-point increase in ethical concern. Both scatter plots had small slopes because the range of numbers used to represent each variable did not go past 5. However, there was not an extreme relationship between the two. A list of the correlations is shown in Table 11 and scatterplots of all variables are shown in Figure 5.

Table 11. Pearson's correlation of all the variables

| | n | Pearson's r | p | VS-MPR † |
|---|---|---|---|---|
| Knowledge of Nanotech - Mean Religiosity Scores | 157 | -0.089 | 0.266 | 1.045 |
| Knowledge of Nanotech – Mean Ethical Concern | 157 | -0.185* | 0.020 | 4.690 |
| Mean Religiosity Scores – Mean Ethical Concern | 157 | 0.157 | 0.050 | 2.455 |

*p < 0.05

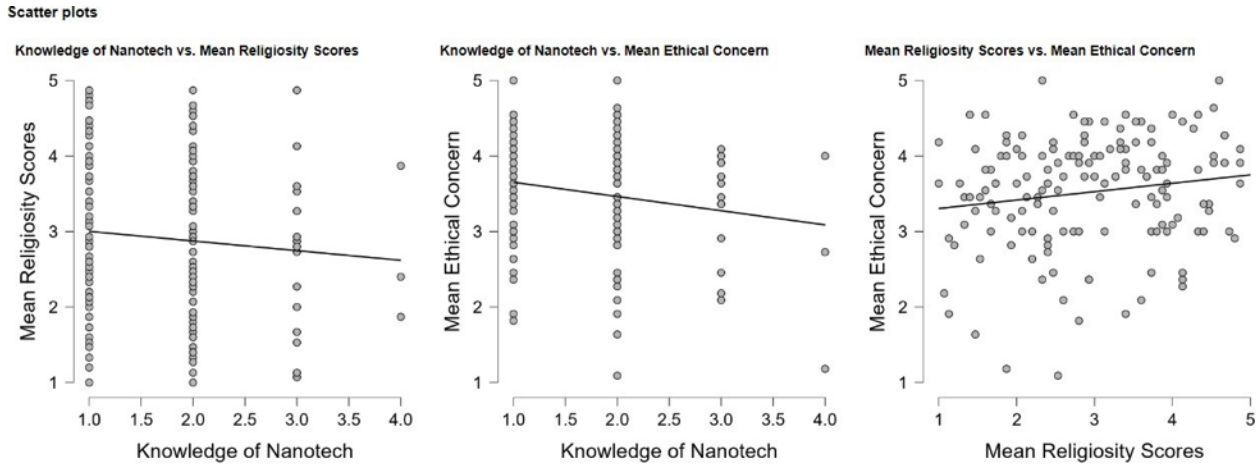


Figure 5. Scatter plots of knowledge of nanotechnology, religiosity, and ethical concern correlated with each other.

Finally, age was also used as a variable to see if any of the prior variables had shown any relationship with age. As shown in Table 12, age was most strongly correlated with knowledge of nanotechnology, depicting that a 1-point increase in age was linked to a 0.201 increase in knowledge of nanotechnology. The p-value = 0.011 which is very close to 0.01 meaning that the data is relatively significant. The Pearson's r-value = 0.201 which represents a slight positive correlation between the two variables.

Table 12. Pearson's correlation of all the variables including age

| | Pearson's r | p | Lower 95% Cl | Upper 95% Cl |
|---|---|---|---|---|
| Knowledge of Nanotech - Mean Religiosity Scores | -0.074 | 0.351 | -0.226 | 0.082 |
| Knowledge of Nanotech – Mean Ethical Concern | -0.176* | 0.026 | -0.322 | -0.022 |
| Mean Religiosity Scores – Mean Ethical Concern | 0.137 | 0.083 | -0.018 | 0.286 |
| Ages – Knowledge of Nanotech | 0.201* | 0.011 | 0.048 | 0.345 |
| Ages – Mean Ethical Concern | 0.033 | 0.682 | -0.123 | 0.186 |
| Ages – Mean Religiosity Score | 0.012 | 0.879 | -0.143 | 0.166 |

* p < 0.05

## 4. Discussion

Upon analyzing the statistical results found, there was only a statistically significant difference between religiosity and the religions mentioned, a slight negative correlation between knowledge of nanotechnology and mean ethical scores, and a positive correlation between increasing age and knowledge of nanotechnology. Primarily, the findings suggest that the religions tested have differing religiosity scores which may play a role in their connection with science and moral understanding of

technology (Franz Foltz and Fredrich Foltz, 2006). Additionally, Brossard, Dominique et al. 2009, had studied that lower knowledge of nanotechnology meant lower reasons to support it, which agrees with the data as there was a negative correlation between the two. However, unlike the results of this study, her study utilized a hierarchical ordinary least squares (OLS) regression to find that lower knowledge of nanotechnology was often paired with higher levels of religiosity. In this study, there was a small negative correlation between knowledge and religiosity which was consistent, but the correlation was too close to zero to say it was significant. The observations found from the other variables including religiosity vs. ethical concern (positive correlation) also agreed with previous studies, but the correlation coefficient was not large enough to show a prominent relationship.

Overall, through ANOVA, this study identified that there were statistically different religiosity scores present in each religion, but there was no difference in knowledge scores across those religions. By doing a Pearson's Correlation, there only seemed to be slight evidence pointing to an agreement in previous trends among my variables, with the strongest being knowledge vs. mean ethical concern. The ambiguous and weak relationships among students compared to adults may suggest that adolescents use more affective or emotional factors rather than cognitive and sociocultural factors when identifying their perceived ethical concern toward nanotechnology, according to Nano- PAAF (Pillai & Bezbaruah, 2017). A lack of understanding about nanotechnology, despite including an information page, may have also contributed to their limited perception of nanotechnology, hence, accounting for the negative correlation between knowledge and overall ethical concern.

When looking further into the potential ethical dilemmas, nanotechnology getting into the "wrong hands" and the loss of freedoms and privacy seemed to be the biggest issue concerning adolescents rather than the social footprint or even the long-term health effects of nanotechnology. This suggests that teens care more about drastic future implications or a sense of "evil" that may polarize the use of nanotechnology, instead of direct implications. Contrasting the findings, Macoubrie (2006) had found that the adults in her study were concerned about the long-term health issues and military uses of nanotechnology, while even the social footprint category appeared to have a high frequency in her study. Each ethical concern was also correlated and there was mostly a significant positive association among all of them, with loss of freedoms vs. lack of regulation having the highest p-value and thus, having the strongest correlation.

### 4.1 Implications

Although some results found in this study were not significant enough to make a conclusion, the general trends do show some similarities between prior studies, suggesting a need to further explore the relationships between adults and adolescents within their understanding of nanotechnology and the ethical concerns it poses. Since there was a clear difference in ethical concerns that students prioritized, future research can help address those issues in ways that specifically cater to their knowledge of nanotechnology and religiosity. The nanotechnology engagement project can also be expanded into classroom settings since the lack of knowledge found by students in Granada Hills poses the need to introduce modern technological advancements like nanotechnology into the school curriculum (Pidgeon, Nick et al. 2011). The results of this study provide critical information about the relationship between religion, religiosity, prior knowledge, and ethical concerns of nanotechnology that may be used to drive future studies on greater populations outside Granada Hills, California.

### 4.2 Limitations

While conducting research, I tried obtaining a representative sample by contacting an equal number of teachers from both schools. However, only minimal responses came from School 2, which led to underrepresentation in data from School 2. Although both schools have similar demographics, since they are located in the same area, the unequal distribution of respondents may have skewed the results and led to a less reliable generalization. Additionally, some religions were not included in the statistical analysis

(Mormons, Jews, etc.) because of the lack of data supported by those groups. Therefore, the data may not be completely representative of communities with higher demographics of those religions, and further research must be done to thoroughly analyze those communities.

Another limitation is that the data collection instrument could have been modified better. Primarily, in the Google Form, the information page that discussed the practical and societal uses of nanotechnology was followed right after the section that inquired about the respondent's prior knowledge of nanotechnology. Therefore, participants could have easily changed their responses after knowing the premises of nanotechnology, skewing the data about their knowledge of nanotechnology. Secondly, the nanotechnology information page could have been adjusted to include links and resources that the students could go to if they did not understand what was on the page, as many participants in the pilot test overlooked or could not understand the nanotechnology information page properly. With a well-written information page, students could have had a clear understanding of the uses of nanotechnology and properly identified what ethical concerns meant the most to them instead of randomly inferring.

Finally, Nano-PAAF stresses the importance of other factors that go into the perceptions of nanotechnology, other than the ones studied in this paper (Pillai & Bezbaruah, 2017). These factors could have an equal or more influential impact on students' ethical concerns about nanotechnology, such as their political views, gender, intake of scientific media, affective values, etc. This study did not analyze these factors because some are more subjective and harder to quantify, while others cross the ethical boundaries of the participants.

## 5. Conclusion

Overall, this study examined a few of the several factors that affect people's perceptions of nanotechnology and found a relationship between religiosity and religion, the various ethical concerns, and weaker correlations between knowledge, religiosity, and ethical concern. The gap was further analyzed as I concluded that adolescents did have similar trends between the variables as adults, except their ethical concerns were centered more around a sense of "evil" or drastic polarization of nanotechnology use. Therefore, the study's findings can be used to create more educational programs around the acceptance and integration of nanotechnology, so that students are less fearful and unaware of nanotechnology. The worldwide acceptance of technology can be improved by examining religion and religiosity further and adapting products to address the ethical concerns of people from different religions.

In the future, more research should be conducted on adolescents in different areas of the United States using a greater sample population since the rising technology industry will be directed and established by the newer generations. To build on this research, the affective factors (ex. hope, expectations, fears, feelings) should be correlated with the variables mentioned in this paper to improve the knowledge known about students and their growing perceptions of nanotechnology. Finally, a focus group could be beneficial for conducting more research since students sometimes feel more comfortable and informed around their own peers who are all on the same page, rather than individually.

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