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# Teaching the Science of Water Fluoridation: A Critical Analysis of Biological Education and Health Policy

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## ABSTRACT

**Purpose:** This study aims to understand the impact of inter-disciplinary approaches, specifically scientific education, ethical reasoning, and global policy perspectives, in the water fluoridation science education. Using the 5E instructional model and Faden & Beauchamp's ethical framework, the study demonstrates how students can interpret the biologics of fluoride as well as the ethical and political influences surrounding its use.

**Methods**: In China, this research was conducted with Science Educator, Health Policy Official, Researchers and Unemployed in provinces like Guangzhou, Shanghai and Beijing. Conducting this research in Guangzhou, Beijing, and Shanghai is strategic because these cities are China's major urban centers with significant influence on national policies and education.

**Results:** The study found that upon completion of the course, the students' assessment of safety of the fluoridation science was enhanced greatly due to scientific education. In addition, ethical reasoning and global policy awareness were also found to have a positive effect on perceived credibility. It is also noted that cognitive engagement moderated the relationship between perceived credibility and understanding of fluoride science.

**Conclusion:** It is this approach that enables students to grapple with some policy debates such as the water fluoridation policy without shying away.

***Key-words:*** Scientific Education, Global Policy Awareness, Perceived Credibility, Understanding Fluoride Science, 5E model

## 1 Introduction

Fluoride is a mineral found in surface and ground water in varying quantities all over the world. It was some time in the early 20th century that Dental Fluorosis associated with fluoride was first recognized as occurring in the human populations as Dr Frederick McKay noticed in "Colorado Brown Stain" where there was a high content of fluoride in water [1]. In the next studies, it was shown that F in the optimum amounts can improve the resistance of the teeth to decay by the process of caries demineralization, and by the case of limiting the teeth demineralization [2]. By the mid 20$^{th}$ century, water fluoridation policies were initiated which sought to increase level of fluoride, aiming to adjust fluoride levels to an optimal concentration of about 0.7 parts per million (ppm). This amount is considered a threshold towards the total eradication of the epidemic of dental caries while curing other dental disfigurements of ingestion of fluorides including dental caries. Epidemiological studies in many countries have clearly shown the importance of water fluoridation in the promotion of oral hygiene by for example lowering the prevalence of dental caries.

When it comes to public health measures, water fluoridation stands out as one of the most effective cost-saving measures, which has been advocated for the prevention of dental caries mostly in underserved populations. Supported by organizations such as World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC), supports fluoridation as being safe and effective as a measure aimed at improving dental health [3]. Despite its widespread acceptance, yet it is not free from ethical and scientific controversies. It has been argued that mass fluoridation circumvents personal choice as people do not give permission in an overt manner [4]. Some concern about fluoridation is related to its mass administration because of the lack of implicit or explicit informed consent. More importantly, issues like dental and skeletal fluorosis and the long-term effects of fluoride on the brain make this debate worth it.

Considering the uncertainties and even controversies as to effectiveness, efficiency and possible risks to health [5] such as those mentioned, it is not surprising that community water fluoridation raises important moral dilemmas [6]. Fluoridation is not an acceptable public health measure in countries such as Germany, Sweden, the Netherlands [7] where such measures bear political, social and ethical implications. Furthermore, water fluoridation has primarily, in the context of academia been presented as solely a science where its biological impact and advantages in the realm of public health are emphasized. The risks posed by the public health measures, especially those that change the health status of the masses in the absence of individual acceptance, calls for a deeper perspective that involves both factors[8]. With reference to water fluoridation, and most importantly, the community consent for its application, this lead the sociopsychological aspects of the content. Few scholars incorporate these issues, especially for urban school pupils, about public consent, respect and individual rights, and public benefit versus the need for individual choice within normal science and public health courses. Such students will be ill equipped to respond to those multi-angled public health interrogatives owing to lack of a didactic exposure to metrics of these issues, as shown in Figure 1.

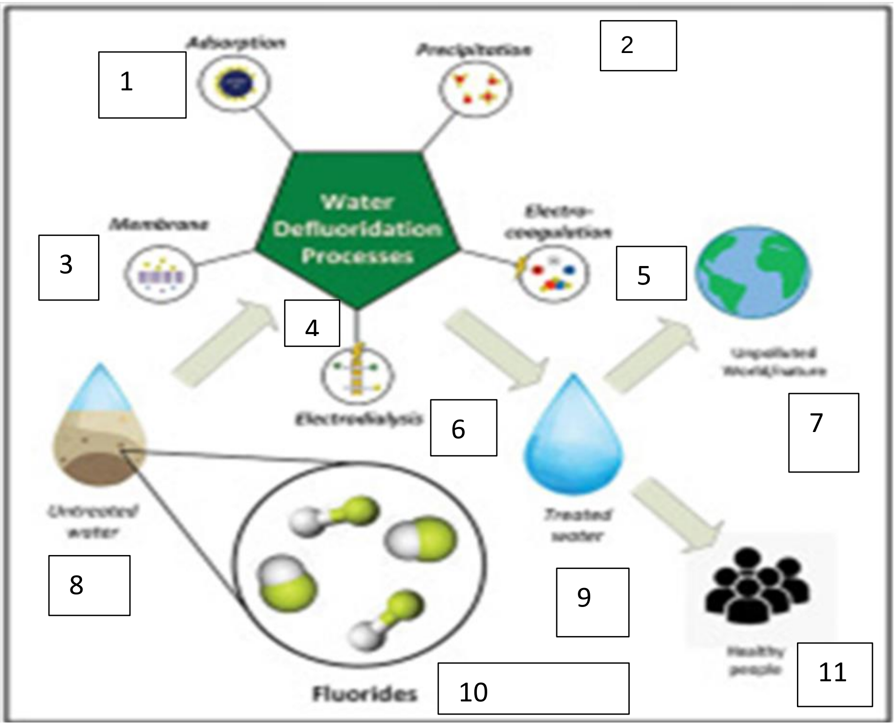


**Figure 1:** Fluoride-containing water: A global perspective and a pursuit to sustainable water defluoridation management ([9] (https://www.sciencedirect.com/science/article)

1. Adsorption
2. Precipitation
3 Membrane
4. Water defluoridation processes
5. Electrocoagulation
6. Electrolysis
7. Unpolluted world/Nature
8. Underground water
9. Treated water
10. Fluorideds
11. Healthy people

The distinctiveness of this study lies within sharing how to teach water fluoridation, synthesizing its science and its moral aspects. Instead of dealing with only biological aspects, this study offers an educational model which encompasses discussions on informed consent, public health ethics and contrast to other countries' policies with respect to water fluoridation if benefits outweigh risks.

This cross-cutting framework is built upon the fusion of two well recognized concepts – the 5E Instructional Model and Faden and Beauchamp's Informed Consent Ethics Framework. The 5E Instructional Model encourages an inquiry-based approach, engaging students in exploring the biological mechanisms of fluoride and its public health benefits, while also guiding them to evaluate the ethical dimensions of fluoridation through hands-on activities, case studies, and discussions. Conversely, Faden & Beauchamp's Ethical Framework offers a structure for teaching students about the ethical dilemmas that arise when public health interventions are implemented without individual consent, focusing on the tension between individual rights and public good, as demonstrated in Figure 2.

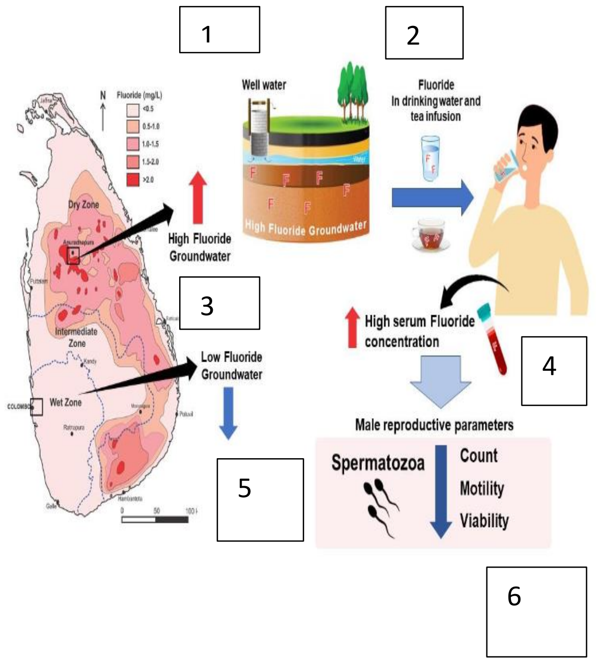


**Figure 2**: Impact of Fluoride Exposure on Male Reproductive Parameters. [9] ([https://link.springer.com/article](https://link.springer.com/article))

1. Well water
2. Fluoride in drinking water and tea infusion
3. High fluoride groundwater
4. High serum fluoride concentration
5. Low fluoride groundwater
6. Male reproductive parameters

Spermatozoa: count, motility, viability

In this study, curriculum policy variations are integrated into learners' education so as to orient them to the political and cultural dynamics that surround the health issue, which would explain why some countries support fluoridation while others don't. Health professionals and biologists almost routinely teach the concept of fluoride water fortification program. However, this tends to focus more on the scientific detailing of the intervention strategies rather than the strategies that outline the ethical and policy approaches [10]. This creates a significant gap in students' ability to critically engage with public health controversies, such as water fluoridation, which involves rather a, difficult conceptual history of the policy dilemma within an ethical framework. Health- aware students should indeed be prepared to deal with political aspects as well as scientific aspects considering the balance of individual liberty and public health policy [8]. This research answers the following questions: 1. Do ethical discussions and global policy context lead to the development of the critical thinking abilities of the students regarding water fluoridation teaching? 2. How does the participation of students interact with the integration of water fluoridation teaching with ethics and policy and the students' external development of critical thinking and ethical reasoning? 3. What impact does active learning have towards students' powers of assessment in terms of the merits and demerits of public health measures like fluoridation of water?

## 2. Theoratical Background

In the teaching of water fluoridation science, it is important to further understand the complexity of this issue. Water fluoridation represents a cross section of science, ethics, teaching and public policy, which transcends pure biological processes [11]. It should be pointed out that adequate teaching strategies on this issue should combine, and not simply state, the scientific information and critical and ethical dimensions encouraged by the inquiries [12]. As they combine educational models and theories on ethics, teachers help students to acquire the frameworks that will enable them to address the societal aspects of public health initiatives such as water fluoridation. The 5E instructional model—Engage, Explore, Explain, Elaborate, and Evaluate—is rooted in constructivist learning theory, which posits that learners construct new knowledge based on their experiences and prior understanding [13].

A desirable feature of water fluoridation from the public health point of view is the prevention of dental caries where there is limited access to dental care. This is why this practice is supported by such health authorities like the World Health Organization (WHO) and the Centres for Disease Control & Prevention (CDC). In an educational milieu, the 5E instructional or root model namely Engage, Explore, Explain, Elaborate and Evaluate models may be used to teach pertinent concepts i.e. water fluoridation [14]. This model allows students to pass through clinical stages of learning of the subject of fluoride e.g. how fluoride affects the tooth as a tissue and evaluating the history of fluoride use against the context of history of public health [15].

The educators will be able to comprehend better the importance of the scientific aspect and the socio-political aspect of the problem of water fluoridation through the application of the 5E model [16]. In the Engage phase, students consider the global discourses on water fluoridation and analyze its implementation with regards to its conceptualization, ethics and the discourse [17]. Further on, in the engagement students explore the chemical composition of fluorides and their efficacy with regard to tooth enamel through experiments and research case studies, fabricating scientific knowledge base. In the Explain phase, learners present the reasons about how the application of fluoride helps reduce dental caries with the help of teachers who start using text and definitions. The Elaborate phase includes maturity, in which the students put their knowledge to new application contexts, such as assessing the consequences of the fluoridation reversal in other regions. Finally, in the Evaluate phase, assessment/understanding is done towards students and management via dialogue/discourse, projects, or evaluative tests of both scientific and moral/ethical components. To enhance this educational strategy there is a need to include Faden and Beauchamp's Ethical Framework of Informed Consent as public health interventions usually have ethical considerations. [18] Faden and Beauchamp's, in the consent model also goes the extra step to explain that there are two 'modes' of informed consent: autonomous authority and effective control [18].

Their framework advocates for self-governance whereby, people make their own choices about health. Even though the fluoridation of water is conducted at a community level without an intention of obtaining affirmative consent from individuals, practicing this ethic in students is instrumental in letting them appreciate transparency, approaches, and public confidence on the enhancing aspects of health policies. In utilizing the 5E instructional model in water fluoridation, teachers are able to merge Faden and Beauchamp's Ethical Framework and create appropriate conditions for the dissemination of tools that include such contrasting, at first sight, aspects as science and ethics. In this model, students are likely to learn critical thinking and decision making in health-related activities in a more practical context and understand clearly the relevance of healthcare systems in society leading to healthy well-informed engagement in public health debate.

## 3. Model and Hypotheses

### 3.1 Research Model

While looking into the interactions among media framing, agenda-setting, risk perception, political orientation, and the society's view on water fluoridation. The model states that it is media framing and agenda-setting which shape public perception, through the mediating mechanisms of political ideology and risk perception. These relationships are studied with the perspective of mass communication theory and two step flow theory.

### 3.2 Hypotheses

Water fluoridation has been promoted as a health strategy to control the prevalence of dental caries. In spite of this, there are still controversies and fallacies, mainly due to propaganda and the lack of knowledge with respect to the science as stated by Xu et al.[15]. Such gaps can be filled through education most especially in the educational programs in biological sciences where accurate information is supplied, and critical appraisal of public health issues is encouraged [19]. New methods of teaching of biological subjects could easily omit the details concerning water fluoridation which is likely to let the population be less aware about the risks and advantages of water fluoridation [20]. A critical appraisal of educational programs is very important in seeking for weaknesses and points of influence that may shape the students and later the society's mind [21]. Therefore, educational policy guidelines regarding water fluoridation need amending in order to ensure that water fluoridation is one of the engaged topics in the mental discourse of students. (Figure. 3)

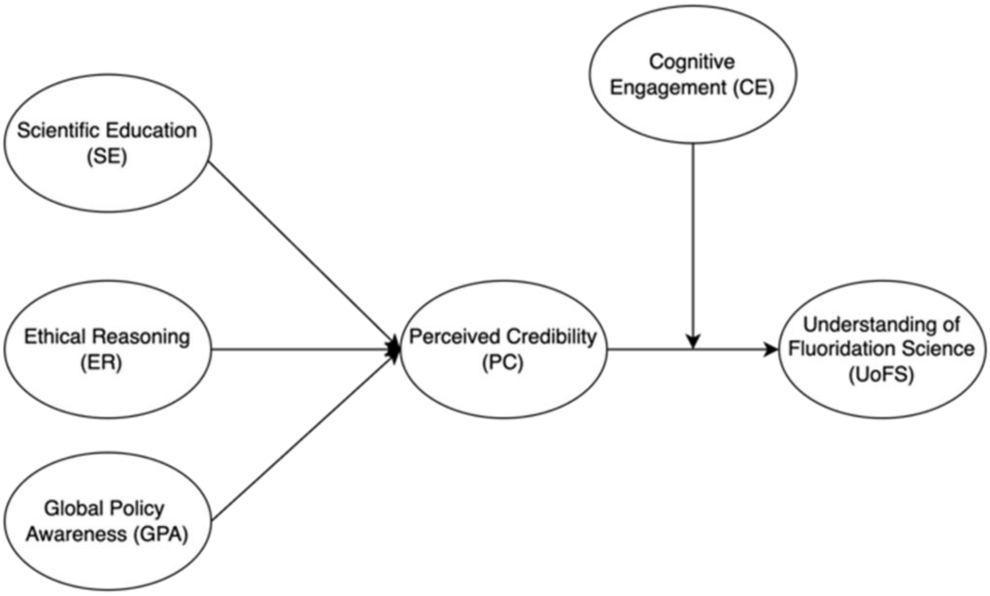


**Figure 3: Proposed model framework**

Scientific education acquires individuals the ability to evaluate health-related information accurately, and that influences their choice of information sources. There may be such a deficiency in fluoridation science where misguided information generates skepticism, but it is hoped that the public will possess enough scientific literacy to enable them to accept the expert opinions. Nisbet and Scheufele [22] argue that the provision of a scientific understanding helps reconcile the public's beliefs with the scientific consensus thus improving their credibility. In the same way, it was discovered [23] that people with a large amount of scientific knowledge are willing to accept the practice of water fluoridation more than others. In this way, the public embrace of scientific education can be said to promote a society that will be able to tell the difference between science and nonsense. Hence, this study proposes the following hypothesis:

***H1: Scientific education positively influences perceived credibility regarding fluoridation science.***

Ethical reasoning facilitates the moral assessment of health measures such as water fluoridation increasing the legitimacy attributed to these interventions. The trust of people improves in the case when these interventions respect ethical principles. For instance, the principle of beneficence seeks to do good while the non-maleficence principle seeks to do no harm. This match of moral beliefs contributes to higher willingness and confidence regarding acceptance of public health initiatives. To help ensure the success of health policies Leader also characterized outcome for perceived justice as increasing public compliance and trust understanding its justification [24]. Emphasizing the ethical aspects of fluoridation, health bureaucrats can bolster the image of this intervention in the eyes of the population.

***H2: Ethical reasoning positively influences perceived credibility of fluoridation science.***

The knowledge of international fluoridation practices and policies allows the individual to place local strategies within a broader context, with the support of a comparative analysis of its practices. This also presents the residents with an opportunity to imagine what successful fluoridation practices may be available elsewhere, thereby enhancing support for such initiatives in their own countries. Where local practices coincide with those that have been proven to work elsewhere, it is more likely that there will be less opposition and higher levels of acceptance [25]. As stated by Petersen and Lennon [26] it is important to note that the presence of the World Health Organization endorsement of fluoridation impacts the countries in terms of policy and public perception. Likewise, Armfield and Akers [27] reported that the residents' knowledge of external advocacy for fluoridation enhances their attitude towards local programs of water fluoridation. So, this study proposes the following hypothesis:

*H3: Global policy awareness positively influences perceived credibility of fluoridation science.*

The more credible people find scientific information, the more willing they will be to work with it and understand it deeper. Assurance for the information sources covering the topic of fluoridation motivates one to look out for its science, thus making people better informed. Brossard and Nisbet [28] stress that as regards scientific information, the tendency to look for more such information and be actively involved in discussions about it was associated with more support for the technology involved. The more attention citizens paid to media coverage of agricultural biotechnol-ogy (with the exception of TV news), the more they knew about the science specificto the debate. And the more they knew about the science of agricultural biotechnol-ogy, the more supportive they were of the technology [28]. Likewise, Kahan et lk. [29] also reported that the aspect of trust in science communication affects the attitude they will have toward understanding the science. It can hence be inferred that any efforts aimed at improving the public perception of the credibility of the science underlying water fluoridation will result in enhanced public reception of the practice." The increase of scientific information credibility will increase the audience's trust and activity towards the science in question.

***H4: Perceived credibility positively influences understanding of fluoridation science.***

The degree of cognitive engagement should also help improve the understanding of fluoridation as a science whereby credibility of the information is perceived. The higher a person's cognitive engagement, the greater the depth of the information processing, and consequently sources' perceived credibility becomes a potent muscle [30]. People become engaged in high levels and therefore, they exert self-control and quality of information from which they learn thus mastering science. This is especially relevant for aspects of public health, such as fluoridation, whereby comprehension of the subject relies on the confidence in its rationale [31]. In contrast, when cognitive engagement is low, even credible information may not significantly impact understanding, as individuals are less likely to invest the mental effort needed to process it fully. Thus, cognitive engagement amplifies the effect of perceived credibility on the depth of understanding in scientific contexts. Therefore, this study proposes the following hypothesis:

***H5: Cognitive engagement positively moderates the relationship between perceived credibility and understanding of fluoridation science.***

## 4. Methodology

In order to validate the proposed research model, we employed a mixed methods approach by utilizing online surveys. In China, this research was conducted with Science Educator, Health Policy Official, Researchers and Unemployed in provinces like Guangzhou, Shanghai and Beijing. Conducting this research in Guangzhou, Beijing, and Shanghai is strategic because these cities are China's major urban centers with significant influence on national policies and education. Each city represents different regions—south, north, and east—providing a diverse cultural and socio-economic backdrop. The next section describes the measures which were used in this study, the samples which were drawn and the methods of getting the data.

### 4.1 Measures

The constructs that were utilized in this survey, in terms of the content validity remained being derived from earlier studies. Items for Construct as per the Table 1. The Scientific Education (SE) scale was borrowed from Nisbet and Scheufele [22] and Allum et al. [23] based on 4 constructs in areas such as science related education on Fluoride. Ethical Reasoning (ER) scale having four constructs was also taken from Faden and Beauchamp [18] and from Childress et al. [24] on understanding the use of fluoride. Perceived Credibility's (PC) four constructs, and Global Policy Awareness (GPA) scales based on five constructs was borrowed from the literature [28][29][32] and [26] [27] respectively related to credibility and policies awareness. Additionally, four constructs of Understanding of Fluoridation Science (UFS) adopted from ten Cate [2] and five constructs of Cognitive Engagement (CE) taken from Fredricks [33]. All these items were using a 7-point Likert scale ranging from 1 = strongly disagree and 7 = Strongly agree.

**Table 1. Measures of Construct**

| Variable | Items | References |
|---|---|---|
| | | |
| **Scientific Education (SE)** | SE1: I understand how fluoride impacts dental health. | [22][23] |
| | SE2: I can explain the scientific basis for water fluoridation policies | |
| | SE3: I am aware of the long-term effects of fluoride on human health. | |
| | SE4: I understand the rationale behind the addition of fluoride to public drinking water. | |
| **Ethical Reasoning (ER** | ER1: I can analyze the ethical implications of fluoridation policies. | [18] [24] |
| | ER2: I understand the importance of informed consent in public health decisions. | |
| | ER3: I can identify the moral conflicts between individual choice and public health benefits. | |
| | ER4: I think individuals should have a choice regarding fluoride in their drinking water. | |
| **Perceived Credibility (PC)** | PC1: I trust the scientific research behind fluoridation practices. | [28][29][32] |
| | PC2: I believe that water fluoridation is an effective public health measure | |
| | PC3: I understand the role of organizations like WHO in promoting water fluoridation. | |
| | PC4: I think fluoridation is a proven method for preventing dental problems in communities. | |

**Table 1 continued. Measures of Construct**

| Variable | Items | References |
|---|---|---|
| | | |
| **Global Policy Awareness (GPA)** | GPA1: I am aware of international policies supporting fluoridation | [26] [27] |
| | GPA2: I can compare global and local fluoridation policies. | |
| | GPA3: I understand the role of organizations like WHO in promoting water fluoridation | |
| | GPA4: I understand how regional policies on fluoridation differ from international guidelines. | |
| | GPA5: I understand how the WHO supports water fluoridation globally as a health measure. | |
| **Understanding of Fluoridation Science (UFS)** | UFS1: I understand the mechanisms through which fluoride prevents dental caries | [2] |
| | UFS2: I am knowledgeable about the chemical properties of fluoride | |
| | UFS3: I can explain how fluoride interacts with tooth enamel to prevent decay | |
| | **UFS4:** I can describe the chemical interaction between fluoride and teeth. | |
| **Cognitive Engagement (CE)** | **CE1:** I am actively engaged in understanding how fluoridation policies impact public health. | [33] |
| | **CE2:** I regularly think about the public health benefits of water fluoridation. | |
| | **CE3:** I critically engage with new information about water fluoridation and its health effects. | |
| | **CE4:** I actively follow discussions about the effects of fluoridation on public health. | |
| | **CE5:** I am intellectually curious about the broader implications of water fluoridation policies. | |

### 4.2 Sample and Data Collection

To collect data for this study on teaching the science of water fluoridation and critically analyzing biological education and health policy in China online questionnaire was used. An initial pilot study with twenty educators and policymakers from **Beijing**, **Shanghai**, and **Guangzhou** helped refine the questionnaire items for clarity and relevance. The finalized survey was distributed over a three-month period starting at the beginning of the 2024 calendar year, reaching out to 700 professionals including science teachers, curriculum developers, public health officials, and policymakers in these major cities. After follow-ups through local educational institutions and community organizations to enhance the response rate, 530 participants completed the survey, and 495 valid responses were obtained after excluding incomplete questionnaires. This substantial sample provided comprehensive insights into current teaching methodologies, educational content related to water fluoridation, and the effectiveness of existing health policies in China's urban centers, forming the foundation for critical analysis aimed at improving biological education and informing future health policy decisions.

The demographic profile of the respondents who participated in the survey is presented in Table 2 below. The majority of respondents were between 25 and 45 years old, with males representing 58% and females

42% of the sample. Most respondents have been involved in their current roles related to biological education and health policy for 3 to 5 years (67%). A significant portion is currently employed as science educators (43%) or health policy officials (38%) in major cities such as Beijing, Shanghai, or Guangzhou. Many have previously resided in these large cities for over five years (59%), bringing valuable urban experience to their current positions.

**Table 2: Demographic Characteristics of Respondents**

| Demographic Factor | Categories with percentage |
|---|---|
| Age Group | 25–35 years (42%), 36–45 years (38%), 46–55 years (15%), 56+ years (5%) |
| Gender | Male (58%), Female (42%) |
| Years Since Return | Less than 1 year (10%), 1-3 years (23%), 3-5 years (67%) |
| Current Employment | Science Educator (43%), Health Policy Official (38%), Unemployed (19%) |
| Previous Residence | Large cities (59%), Mid-sized cities (26%), Small cities (15%) |

## 5. Data Analysis and Results

To evaluate both the measurement and structural model, we utilized SmartPLS version 4.0 to carry out structural equation modeling. It is worth noting that SmartPLS integrates the principal components to build CFA and regression techniques to determine the measurement model and the structural model. Very useful in handling moderating relationships and formative measures. As stated by [34] SmartPLS is not only able to propose a formative model with latent constructs which is rather complicated to handle even for those not proficient with it but does not also make biases relative to the form of distribution of the data. As a result, we employed the use of SmartPLS 4.0 software in carrying out CFA and structural model testing in our study.

### 5.1 Measurement Model

#### 5.1.1 Reliability and Validity

Smart PLS version 4 was employed for the testing of exploratory factor analysis (EFA) to examine if the measurement indicators could exhibit factor loading more than 0.4. The findings are collated in Table 3. The EFA is mostly employed to test the extent to which measurement items associated with certain factors, and to examine further, the relationships between these factors. The EFA findings show that the fit indices for the whole confirmatory model are acceptable, and all factor loadings were above the stipulated 0.7 rule of thumb guideline. Such a statement satisfies concerning the adequacy of the internal structure of the model and the lack of grave cross loading problems.

In terms of indigeneity validity assessment, comparison was done on construct factor loadings, Cronbach's alpha, composite reliability (CR) and average variance extracted (AVE). In table 3, loadings and Cronbach's alpha and CR and AVE are provided for each construct. It was noted that all item loadings are well above the standard 0.7 level for reliability of items. It was observed that the values of Cronbach's alpha ranged between 0.836 and 0.873 which is acceptable for reliability of measurements across the different constructs. The internal consistency was confirmed as the composite reliability (CR) values were above the threshold of 0.7 ranging from 0.843 to 0.877. The average variance extracted (AVE) values also known to reflect average amount of variance explained by a particular set of items per construct also largely exceeded the recommended threshold of 0.5 from 0.604 to 0.728 indicating comprehensive convergent validity that was established (see Figure 4).

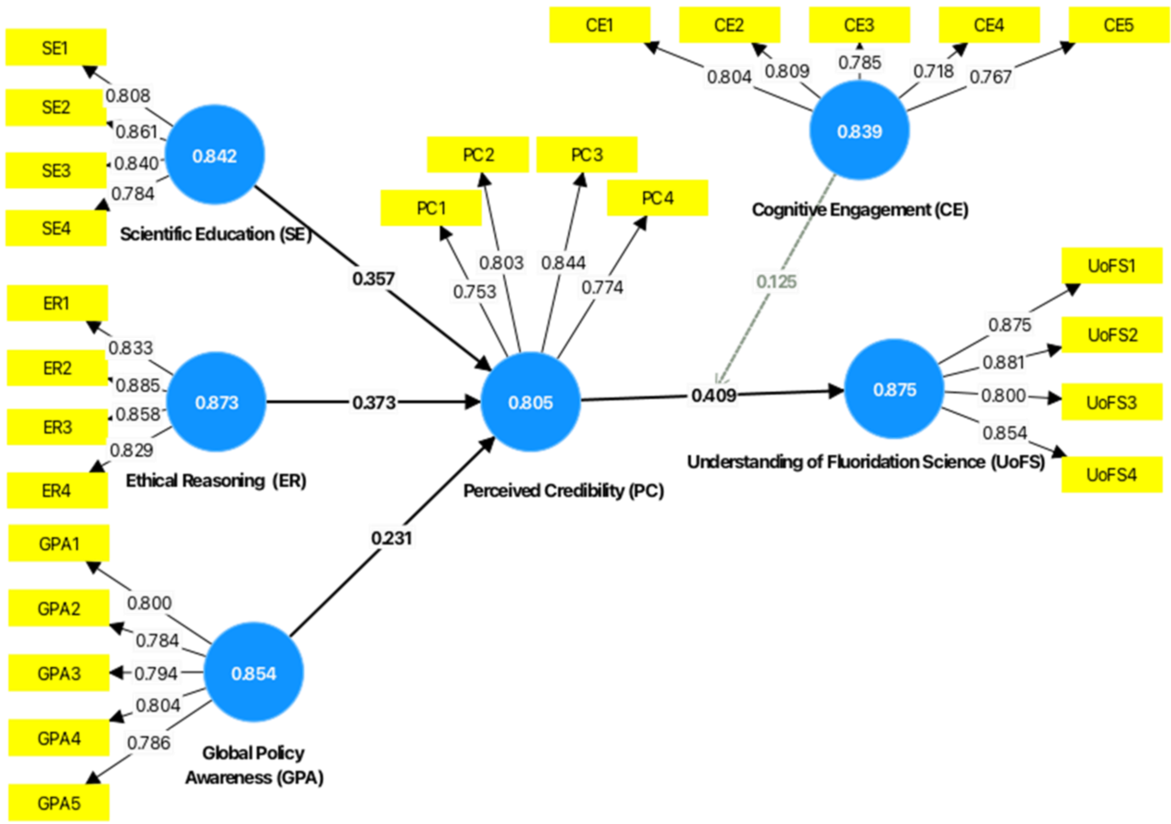


***Figure 4:*** *SEM Showing factor loading and path coefficient among latent variables and observed variables.*

Table 3: Construct Reliability and Validity

| Constructs | Items | Loading | Cronbach alpha | CR | AVE |
|---|---|---|---|---|---|
| Ethical Reasoning (ER) | ER1 | 0.832 | 0.873 | 0.875 | 0.725 |
| | ER2 | 0.885 | | | |
| | ER3 | 0.857 | | | |
| | ER4 | 0.830 | | | |
| Understanding of Fluoride Science (UoFS) | UoFS | 0.874 | 0.842 | 0.877 | 0.728 |
| | UoFS | 0.880 | | | |
| | UoFS | 0.801 | | | |
| | UoFS | 0.855 | | | |
| Global Policy Awareness (GPA) | GPA1 | 0.797 | 0.854 | | 0.630 |
| | GPA2 | 0.782 | | | |
| | GPA4 | 0.805 | | | |
| | GPA4 | 0.797 | | | |
| | GPA5 | 0.788 | | 0.861 | |
| Scientific Education (SE) | SE1 | 0.809 | 0.842 | 0.843 | 0.678 |
| | SE2 | 0.862 | | | |
| | SE2 | 0.839 | | | |
| | SE4 | 0.784 | | | |
| Cognitive Engagement (CE) | CE1 | 0.804 | 0.839 | | 0.604 |
| | CE2 | 0.809 | | | |
| | CE3 | 0.785 | | | |
| | CE4 | 0.718 | | | |
| | CE5 | 0.767 | | 0.859 | |
| Perceived Credibility (PC) | PC1 | 0.721 | 0.836 | 0.843 | 0.604 |
| | PC2 | 0.789 | | | |
| | PC3 | 0.780 | | | |
| | PC4 | 0.845 | | | |
| | PC5 | 0.746 | | | |

The square root of the average variance extracted for the actual and the latent construct is used to evaluate discriminant validity. The corresponding measurements are with respect to components, and such an assessment is made through pairwise comparisons of the measures with the square root of AVE for a single construction with the inter-construct correlations. Cognitive Engagement (CE), the square root of AVE is 0.777 which is above the correlation with Ethical Reasoning (ER) 0.681. Global Policy Awareness (GPA) at 0.707 and Perceived Credibility (PC) at 0.699. Moreover, Scientific Education (SE) at 0.654 and Understanding of Fluoride Science (UoFS) at 0.672. Such consistency was also obtained across all constructs as shown in Table 4 confirming that each construct explained more variance in its items than in other constructs.

**Table 4**: Fornell-Larcker criterion

| | CE | ER | GPA | PC | SE | UoFS |
|---|---|---|---|---|---|---|
| **CE** | 0.777 | | | | | |
| **ER** | 0.681 | 0.851 | | | | |
| **GPA** | 0.707 | 0.583 | 0.794 | | | |
| **PC** | 0.699 | 0.779 | 0.657 | 0.777 | | |
| **SE** | 0.654 | 0.676 | 0.572 | 0.750 | 0.824 | |
| **UoFS** | 0.672 | 0.701 | 0.642 | 0.722 | 0.661 | 0.853 |

Additionally, multicollinearity as a dependent variable was measured through variance inflation factor (VIF) between constructs. The VIF scores were within range of 1.000 –2.765 and were all below the acceptable level of 10 which shows that there was no multicollinearity amongst the variables in the study.

Subsequently, the model is tested using the data collected for the validated measures. Some overall fit indices were obtained for the proposed model using SmartPLS 4. The resultant values are according to the acceptable thresholds. For the RMSEA index, the result is 0.078, which is lower than the cut-off threshold of 0.10. Based on the range of values CMIN/DF equals 2.770, which is also considered an acceptable value.

**Table 5**: HTMT Ratios

| | CE | ER | GPA | PC | SE | UoFS |
|---|---|---|---|---|---|---|
| **CE** | | | | | | |
| **ER** | 0.761 | | | | | |
| **GPA** | 0.828 | 0.663 | | | | |
| **PC** | 0.814 | 0.605 | 0.770 | | | |
| **SE** | 0.749 | 0.788 | 0.661 | 0.887 | | |
| **UoFS** | 0.755 | 0.800 | 0.732 | 0.839 | 0.765 | |
| **CE x PC** | 0.276 | 0.347 | 0.238 | 0.347 | 0.273 | 0.407 |

Prior to that, IFI is 0.926, TLI is 0.914 and CFI is 0.926, these all exceed the recommended figures of 0.90 [35]. So therefore, the results support the model fit and it's valid.

Self-reported surveys are a major part of the respondents in this study therefore Harman's one-factor test was conducted to determine common method bias. Results from the test demonstrated that the most influential factor accounted for 36.9% of the total variance which is less than the 50% threshold and this bodes well for the concern of common method bias with this study. Worse still, neither of these nor any other strong inter-construct correlations ($r > 0.90$) was observed in the matrix mitigating common method bias.

**5.1.2 Structure Model**

The research was then conducted on the data derived from the measures which were validated. The overall fit requirements for the proposed model are satisfactory, since the conclusions are within the generally accepted levels. After a fit that was adequate to the model, there were computations of the path coefficients.

The findings indicate that the path coefficients are significant. Scientific Education (SE) has a strong significant positive effect on Perceived Credibility (H1: $\beta = 0.357$, $p < 0.000$) which confirms that students who has scientific education or awareness perceive sources that are credible, and their understanding of fluoride science is stronger. There is also a similarly significant factor that is Ethical Reasoning that affects Perceived Credibility (H2: $\beta = 0.373$, $p < 0.000$) which means that ethical reasoning enhances the credibility. Another factor that further works in the support of credibility is Global Policy Awareness for (H3: $\beta = 0.231$, $p < 0.000$)

in which it is proven that in and understanding of fluoride science is greatly enhanced by the perceived credibility of students. In this vein, perceived credibility further impacts the understanding of Fluoride Science of Students (H4: $\beta = 0.409$, $p < 0.000$). The results also suggest that Cognitive Support acts as a moderator in the relationship between perceived credibility and understanding of fluoride science for students (H5: $\beta = 0.125$; $p = 0.001$). It means that flickers in PC significantly improve the understanding of students in fluoride science only when students perceive credibility of source. For this reason, we accept the verification of the assumed model (Figure 5).

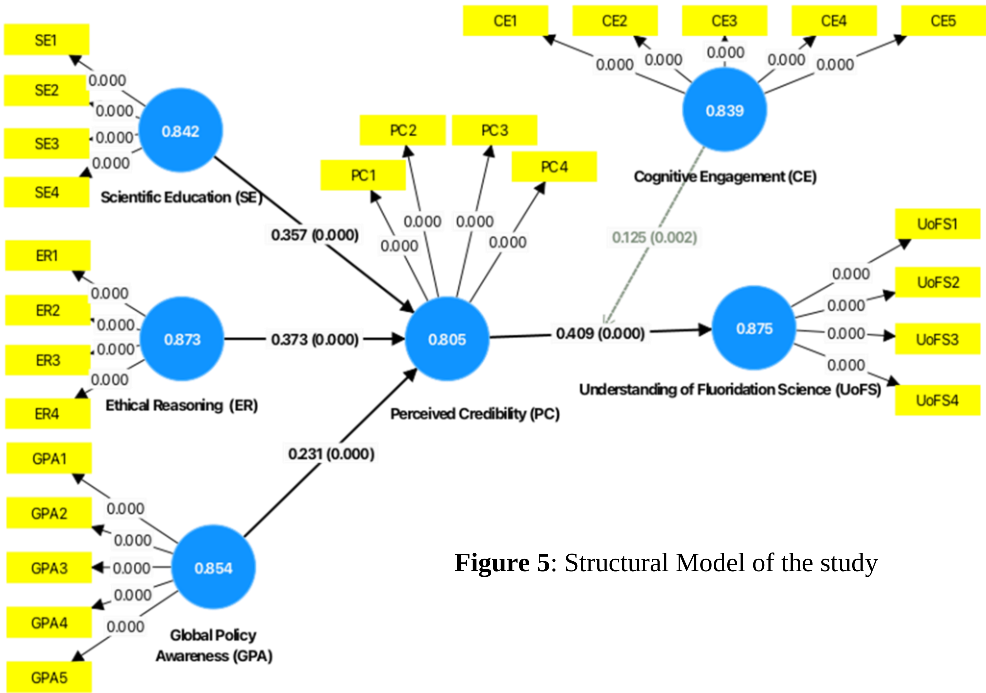


**Figure 5**: Structural Model of the study

## 6. Discussion and Conclusions

This study critically examines the intersection of biological education and health policy, with a particular focus on the teaching of water fluoridation science. By integrating scientific education, ethical reasoning, and global health policy perspectives, the study highlights the complex educational and policy dynamics that shape public health initiatives like water fluoridation. The findings depict that the current model of teaching water fluoridation in biological education primarily focuses on scientific aspects, often overlooking the critical ethical and policy considerations necessary for a more holistic understanding of public health interventions. The study confirms the hypothesis that scientific education plays a significant role in enhancing the perceived credibility of fluoridation science. Students with a deeper understanding of the biological mechanisms behind fluoride's effect on dental health are more likely to trust and accept water fluoridation policies. This is consistent with prior research, which suggests that scientific literacy is key to increasing public acceptance of health interventions [23]. Fluoride’s ability to prevent dental caries through remineralization of tooth enamel is a well-established concept [36] yet, this biological mechanism alone is insufficient for fully understanding the public health implications of water fluoridation[11]. Educational approaches that solely emphasize scientific concepts without addressing the broader ethical and policy dimensions may limit students’ ability to critically engage with public health measures.

### 6.1 Theoretical and Practical Implications

The research has some theoretical implications. Firstly, the findings of this study emphasize the importance of integrating ethical reasoning into the teaching of water fluoridation science. The ethical dimension of water fluoridation, particularly the issue of informed consent and the balance between individual autonomy and the collective good, is often neglected in traditional biological education. Secondly, through the application of Faden and Beauchamp’s Informed Consent Ethical Framework, educators can help students critically analyze the ethical dilemmas inherent in fluoridation policies. This framework encourages students to evaluate public health measures not only on the basis of scientific efficacy but also through the lens of ethical principles such as autonomy, beneficence, and justice [37].The study found that students who are actively engaged in discussions about water fluoridation demonstrate a stronger understanding of its public health implications.

This study concludes that a more integrated approach to teaching the science of water fluoridation—one that combines biological science, ethical reasoning, and global policy awareness—is essential for developing students' critical thinking skills and understanding of public health measures. The traditional model of teaching water fluoridation as a purely scientific concept is insufficient for preparing students to engage with the ethical and policy controversies that surround such interventions. To improve the effectiveness of fluoridation education, educators should adopt a cross-disciplinary approach that incorporates ethical frameworks, policy analysis, and global perspectives into the curriculum [38]. This will enable students to critically evaluate the benefits and risks of water fluoridation, understand the socio-political context of public health decisions, and appreciate the ethical implications of mass health interventions.

### 6.2 Limitations and Future Research Directions

It is concluded from this study that a comprehensive strategy for teaching students about water fluoridation, which emphasizes biological science as well as appreciates moral and international dimensions, would be consequential in developing the students' critical ability. The research shows that knowledge and skills which are scientific are not enough in tackling the issue of oncology and the water fluoridation debacle. With this addition to the curriculum of students, they will be able to take such analyses of risks and advantages in any particular consideration. This multidisciplinary approach sparks attention and activity in public health discussions and qualifies students to resolve ethical issues in future science and welfare policies.

While this study provides valuable insights into the teaching of water fluoridation, several limitations must be addressed in future research. First, the study focuses primarily on urban school settings, which may not reflect the broader diversity of educational environments. Future research should explore how rural and underserved populations engage with the topic of water fluoridation and whether educational interventions can be tailored to meet their specific needs [39]. Future studies should investigate how students' attitudes toward other controversial public health measures, such as vaccination or genetically modified organisms (GMOs), are influenced by similar integrated educational models [40]. Expanding the scope of research to other public health controversies can provide a more comprehensive understanding of how education shapes public health literacy and ethical reasoning across different contexts.

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