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Analyzing the Language of Fluoride Knowledge Education for Children to Understand Public Policy Influences Through Critical Discourse Analysis

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ABSTRACT

Purpose: The early education of children on fluoride typically focuses on the scientific aspects of this phenomenon (fluoride strengthens enamel) but fails to teach the actual policy-making mechanism (who sets the amount of fluoridation) that ensures the safety of the community water supply. Discourse decisions, such as text complexity, issue framing, critical-thinking questions, and visual aids, mediate calls to think and civic education.

Methods: The current study examines the effect of four instructional discourse strategies on self-reported fluoride science knowledge and awareness among elementary school students of the processes involved in fluoride science public-policy decision-making a total of 283 respondents were fourth- to sixth-grade students in a high-fluoride area. Differences in instructional materials by (1) clarity of the text, (2) presence of explicit policy framing, (3) inclusion of critical-thinking questions, and (4) matching between visual aids and instructional materials were observed. Measures of outcomes were based on five-point Likert scales that evaluated both scientific and policy knowledge. SmartPLS was used to analyze the data in terms of measurement validity and the path analysis.

Results: Each of the four discourse strategies poses a strong positive influence on both cognitive and civic outcomes. The most significant increase in scientific understanding was achieved through clear text and visual support, whereas policy framing and critical prompts enhanced students' knowledge of governance processes. The mixing of factors led to synergies of gains in both areas.

Conclusion: Curriculum designers can make fluoride education materials more accessible by incorporating simplified language, clear governance contexts, age-appropriate reflection tools, and affirmative images to help scientifically literate, civically engaged learners. This study provides the first comprehensive initial appraisal of discourse strategies in basic public health education using critical discourse analysis (CDA) within the C-A-C technique.

Keywords: *Fluoride education; critical discourse analysis; text clarity; policy framing; visual support*

INTRODUCTION

Fluoride has been considered one of the most effective public health interventions for preventing dental caries, and community water fluoridation has been supported by the World Health Organization and health agencies worldwide. Younger educational efforts concerning fluoride have an interesting two-pronged goal: providing the groundwork of scientific literacy behind fluoride's effectiveness in strengthening

tooth enamel, as well as preparing the young citizen to make an informed decision about the quality of their drinking water. The discourse strategies embedded, however, in these materials differ a lot (Zhang & Chen, 2024). Others use technical terms that are way beyond the basic reading level, thus causing young learners to experience cognitive overload. Some dumb it down to such an extent that they forget to mention the governance systems, local councils, water authorities, and public health organizations that choose to set

standards for fluoridation. A third type employs engaging narratives or vibrant illustrations but does not facilitate critical reflection on questions such as why fluoride is added to water and who makes those decisions. This can lead to children learning disjointed pieces of knowledge (“fluoride can help teeth”) and creating no coherent vision of the science and the policy-making process that would deliver a safe, fair water supply (Fu, 2024).

This challenge is especially notable in countries such as China and Pakistan. In the provinces of China's countryside, where fluoride levels occur naturally and may exceed safe levels, school lessons (particularly those about fluoride) are frequently constrained in scope, discussing only the chemical benefits of fluoride and saying little about water bureau agencies that administer the dosed quantity. The children are taught not to fear fluoride, but rather that it will prevent cavities; they fail to realize the discussion on the consequences of water-treatment methods held by the local government (Song, 2024; Woodside-Jiron, 2011). In a similar manner, in the Punjab region of Pakistan, most of the population has been afflicted by dental and skeletal fluorosis due to very high levels of fluoride in the groundwater. Health clinics disseminate pamphlets on the benefits of fluoride-containing compounds in toothpaste without mentioning policies on de-fluoridation by the provincial health department. In the two instances, lacking precise policy formulation and critical thinking triggers, young students are left with a shallow understanding of the science of fluoride and no idea of what they could do, as individuals or as groups, to shape the structures of governance that safeguard their water.

This process of dissociation between teaching design and training goals is a significant loophole within the field of public health pedagogy. According to Critical Discourse Theory, learners do not merely build a sense based on the materials, but also with the framing and word choices applied to introduce them. Readability studies also indicate that to enable people to read, understand, and remember what they are reading, the text should be at a level that accommodates the readers' grade level (Wang et al., 2025). In the meantime, after studying the relevance of civic engagement, one can conclude that early exposure to policy contexts (when they are scaffolded, of course) leads to a sense of agency and trust in public institutions. However, it is D2 i, in combination with these four dimensions of the discourse (language clarity, explicit policy processing, critical-thinking invitations, and graphic illustration) that are rarely combined into a unified, devoutly adaptive curriculum when educative materials on the subject of fluoride are developed. Losing such integration would leave children scientifically knowledgeable in a restricted sense, but leave them civically indifferent or civically

engaged yet lacking in essential fluoride basics (Cao, 2024).

The absence of empirical data, therefore, on the collective and interactive effects of particular discourse strategies in fluoride-educational materials on the cognitive action of fluoride science in the minds of elementary-grade learners, as well as the civic action of fluoride-governance processes, thus becomes the research problem. To address this, the main research question is: How do the differences in clarity of the text, framing of the policy, provision of critical-thinking prompts, and visual aids influence children's self-reports of understanding fluoride science and knowledge of fluoride-related public policy mechanisms? By creating the intersection between discourse theory and the practice of public health, answering this question will help close the gap between the two.

The ultimate goal of the study is to formulate evidence-based recommendations to guide the design of fluoride-education materials that best promote dual learning outcomes in elementary students, namely strong scientific literacy and adequate civic literacy. There are three new contributions to our study. Our experimental design is a fully factorial 2^4 , capable of separating not only the individual effects of four of the most essential discourse elements but also their combined effects. This methodological innovation is a novel approach not previously used in the design of a public-health curriculum. Second, we make policy framing our explicit variable, which was previously an implicit background context in research, to determine whether children can handle ideas of governance in a consequential manner, both in context and with scaffolded, deliberate development in a developmentally appropriate manner.

Third, we are presenting critical-thinking prompts to young learners with age-specific questions that form the basis of curiosity and confidence—a feature prevalent in post-secondary education but underutilized in K-12 health learning resources. Conseils or combinations of features that have the most powerful learning and engagement effects will be identified by systematically manipulating these four factors across sixteen instructional conditions and measuring cognitive (self-reported understanding of the role of fluoride in the prevention of caries) and civic (self-reported knowledge of the decision-making process of water-authorities) outcomes on five-point Likert scales. The results will be used to develop more effective and policy-sensitive fluoride-education materials, which will help create scientifically literate and civically vigilant future generations.

LITERATURE REVIEW

Cognition–Affect–Conation (C–A–C) Framework

Educational psychology established three intertwined dimensions of human response cognition, affect, and conation as key to learning and eventual behavior long ago. Cognition refers to the cognitive processes of knowing, involving the perception, processing, and understanding of information. Affect refers to the feelings about that information, whether of interest, curiosity, or boredom. Conation refers to motivation toward action, encompassing the willingness to apprehend, disseminate, or acquire more information (Li et al., 2025).

Following this model, which consists of three parts, researchers have employed the C-A-C model to describe the role of instructional design in educational achievement. Beliefs (cognition) in the Theory of Reasoned Action (Han & Choi, 2019) form attitudes (affect), which then influence behavioral intentions (conation). Similarly, according to the Technology Acceptance Model (TAM; Davis, 1989), a positive attitude (affective response) depends on the perception of utility and ease of use (cognitive beliefs), which in turn leads to the intention to adopt a new technology (conation). In fields ranging over customer loyalty to persistence in using information systems (Chang et al., 2025; Tang, 2024), the C-A-C framework has proven its effectiveness in explaining the correlated linkages between cognitive appraisal and emotion response in mutually motivating behavior.

Applied to fluoride education, this model proposes that when children perceive the text's legibility and policy applicability (cognition), their emotional connection with the text (interest, curiosity, or confidence) initiates their desire to learn and use fluoride facts (conation). Because these elements of our instructional variables (language clarity, policy framing, critical prompts, and visual support) have a clear cognitive and affective explanation, we can more accurately anticipate conative consequences, such as self-reported mastery of fluoride.

Integrative Implications for Fluoride Education

All the literary sources point to the same direction: a discourse-driven approach. Simplify language to maximize cognition, ground the subject matter locally as policy to build civic context, activate critical thinking to engage emotions, and utilize imagery to facilitate dual coding. However, none of the past research has experimentally tested these four dimensions together, especially in young learners at a public health level. Our study therefore addresses an essential lacuna since we used the C A C framework to elucidate the education on fluoride construct effectively by creating positive emotions through critical prompts and images, resulting in conative developments or children reporting themselves to have mastered fluoride

science and being fully aware of fluoride policy. In this way, we apply discourse-analysis techniques to health-education studies and offer practical advice to curriculum designers and practitioners in the field of public health interested in creating more effective fluoride education resources grounded in an ethos of equity.

HYPOTHESIS DEVELOPMENT

Text Clarity and Fluoride Understanding

An extensive body of scholarly work in readability and learning sciences illustrates that when instructional content is written using simple wordings, sentences, and definitions, free of cognitive overload, and at a reading level appropriate for the target learners, it enables them to comprehend comprehensive materials more effectively. Muangkammuen et al. (2020) demonstrated that matching a text to the reading ability of the recipient significantly increased recall and comprehension. Very recent meta-analyses have indicated that simplifying jargon and streamlining it logically improves children's understanding of the nature of scientific concepts. Translated to fluoride education, if the essential terms, such as fluoride, mineralization, and public health, are defined and embedded into age-relevant examples clearly, then young students will be able to develop proper mental models of fluoride chemistry and its application in community water treatment with high probability.

H1. Materials with higher text clarity will lead to greater overall understanding of fluoride science and policy among elementary school students.

Policy Framing and Fluoride Understanding

The body of research on civic education emphasizes how the integration of scientific issues into the environment that learners encounter in their everyday governance enhances engagement and knowledge transfer. Such case-based research on local policy choices reveals that students gain a better understanding of the procedure when exposed to how scientific recommendations are implemented as policies to be acted upon in municipalities (Van Lieshout et al., 2012). By describing fluoride as not an issue of a chemical additive, but rather a matter of community decision-making, with the implication of water boards' involvement, the public's participation through forums, and the inclusion of health advisory panels, educational materials will help clarify the relationship between science and policy. This two-pronged approach helps students understand the value of the selection made in levels of fluoride dosing, who makes this decision, and how community voices influence the outcome.

H2. Materials featuring explicit policy framing will lead to a greater overall understanding of fluoride science and policy among elementary school students.

Critical-Thinking Prompts and Fluoride Understanding

Research on educational psychology confirms that well-located reflection questions promote the metacognition process and further the development of conceptual understanding. Not only has Richardson et al. (2013) demonstrated that requests to come up with explanations improve the retention and transfer of knowledge, but newer work has indicated that prompts requesting why and how thinking may develop in students enhance a capability of relating factual content to systemic themes. For example, consider framing short prompts, such as: Why do some people in the community disagree with adding fluoride to drinking water? Or What does the education on fluoride have to do with our taxes? A way of inviting students to think along the lines of both chemical processes and civic implications, with both aspects being conspicuously strengthened as a result.

H3. Materials incorporating critical-thinking prompts will lead to a greater overall understanding of fluoride science and policy among elementary school students.

Visual Support and Fluoride Understanding

Dual-coding theory argues that linking words with appropriate graphics, such as diagrams, flowcharts, icons, and overlays, mental representations that reinforce learning. It has been shown that information is more accurately recalled when text and images are combined (Cohen & Demchak, 2018) and that a well-designed image can minimize extraneous processing, resulting in schema formation (Mayer, 2005, cognitive theory of multimedia learning). To illustrate, enamel-tooth cross-sections and fluoride ion paths could bring to life abstractions in fluoride teaching, as well as step charts of the process and chain diagrams of water treatment.

H4. Materials enriched with aligned visual support will lead to a greater overall understanding of fluoride science and policy among elementary school students.

METHODOLOGY

Measures

The study design consisted of four research variables: text clarity and policy framing, critical-thinking prompts, and visual aids as independent

variables, and student understanding of fluoride science and policy as the dependent variable. All independent variables were assessed using four items based on existing educational and readability scales, and the dependent variable was evaluated using five items designed to determine both the speed of understanding and procedural knowledge. These are all presented in Table 1. Items that measured text clarity were adapted using the Cloze readability tests and contemporary readability criteria, which assess ease of vocabulary and sentence construction. Items used in policy framing were based on indicators of civic education, participatory understanding, and community input, emphasizing the activities of local decision-makers and community engagement. Self-explanation and metacognition scales were used as the basis for critical thinking by prompting students to explain cause-effect correlations. To measure the correlation between the text and the diagrams, visual support items were modified by multimedia research on learning. Fluoride understanding objects were a mixture of fact statements (e.g., Fluoride strengthens the tooth enamel) and policy-awareness statements (e.g., The health boards in the locality make decisions on the levels of fluoride in drinking water). The respondents were asked to indicate their level of agreement using a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). All items were reviewed for content validity and age appropriateness by a panel of four elementary educators and two curriculum specialists. A pilot test among thirty-fifth-grade students revealed the clarity of the items and required minor changes in wording.

Sample and Data Collection

In June 2024, data were obtained from four elementary schools in Shangxi Province, where groundwater naturally contains high levels of fluoride. District procedures ensured the consent of parents and assent of children. A final sample of 283 questionnaires was obtained after discarding 17 others based on the proportion of missing or similar answers to questionnaires distributed to fourth through sixth-grade students. Demographic characteristics have been summarized in Table 2. The sample consisted of 52 percent males and 48 percent females, with 42 percent of those aged between 9 and 10 years and 58 percent between 11 and 12 years. Distribution by grade was even between grades 4-6 (33-34 percent each), and 87 of them had lived in the area for at least 5 years. The surveys were conducted by research assistants in the classrooms, and participants were encouraged to provide honest answers confidentially.

Table 1. Measurement Items for All Constructs

Construct	Item	Source
Text Clarity	TC1: "The words in the fluoride lesson are easy to understand."	(Muangkammuen et al., 2020)
	TC2: "Sentences about fluoride are short and clear."	
	TC3: "I can read the entire fluoride text without difficulty."	
	TC4: "New vocabulary is explained clearly in the lesson."	
Policy Framing	PF1: "The lesson explains who makes decisions about fluoride in water."	(Van Lieshout et al., 2012)
	PF2: "I learned how community members can give input on fluoride levels."	
	PF3: "The role of local health boards is clearly described."	
	PF4: "I understand how policy makers use science to set fluoride standards."	
Critical-Thinking Prompts	CTP1: "The lesson asked me why some people might oppose fluoride in water."	(Richardson et al., 2013)
	CTP2: "I was asked to explain how fluoride protects teeth."	
	CTP3: "The text encouraged me to consider pros and cons of fluoridation."	
	CTP4: "Questions prompted me to connect fluoride chemistry with public health."	
Visual Support	VS1: "The diagrams match the text about fluoride action."	(Cohen & Demchak, 2018)
	VS2: "Charts show how fluoride flows through water treatment."	
	VS3: "Pictures help me understand fluoride's effect on teeth."	
	VS4: "Visual aids illustrate the decision-making process clearly."	
Fluoride Understanding	FU1: "Fluoride helps make enamel stronger."	(Leung et al., 2023)
	FU2: "Too much fluoride can cause health problems."	
	FU3: "Local boards decide fluoride levels by reviewing water tests."	
	FU4: "Community feedback influences fluoridation policy."	
	FU5: "I know where to find information about fluoride policy in my town."	

Table 2. Demographic Characteristics of the Sample (N= 283)

Characteristics	Category	Frequency	Percentage
Gender	Male	147	52%
	Female	136	48%
Age group (years)	9–10	119	42%
	11–12	164	58%
Grade level	Grade 4	94	33%
	Grade 5	96	34%
	Grade 6	93	33%
Residence duration	< 5 years	37	13%
	≥ 5 years	246	87%

DATA ANALYSIS

SmartPLS was used to analyze the data. The initial screening was conducted to address missing data (<2% per question), normality, and univariate outliers. Reliability was assessed using Cronbach's alpha, and convergent and discriminant validity were evaluated

through confirmatory factor analysis (CFA), with the results interpreted in terms of fit indices (2/df, CFI, TLI, RMSEA, and SRMR) relative to the established criterion. Construct validity was also confirmed by composite reliability and average variance extracted (AVE). Direct effects were tested using hierarchical multiple regression. Demographic controls (age, gender, grade,

and residence duration) were included in the first block, and each independent variable was entered in turn in the subsequent blocks. Hypothesis support was determined at $p < 0.05$ using path coefficients and p-values. CFA addressed missing data through maximum likelihood estimation with complete information.

The lead researcher had been granted ethical approval by his Institutional Review Board, and the data collected met the requirements of the Declaration of Helsinki. The data and syntax to generate the analysis will be deposited in an open repository in an anonymize form to promote transparency and replication.

Measurement Model

SmartPLS 4 was used to assess the measurement model, examining aspects of indicator reliability, internal consistency, convergent validity, and discriminant validity. The reliability of the indicators was determined by the outer loadings, as presented in Table 3. The standardized loadings of all 20 items are relatively high, 0.901 (VS3) to 0.986 (FU3), compared to the minimum required value of 0.70, indicating that

each indicator is a decent measure of its corresponding latent variable (Table 3).

The internal consistency of the reliability was assessed through Cronbach's alpha and the composite reliability (2c), which are also presented in Table 3. Each construct surpasses the value of 0.70: Cronbach alpha demonstrates the level between 0.849 (Critical Thinking Prompts) and 0.975 (Text Clarity), and composite reliability equals 0.862 (Problem Posing Style) to 0.982 (Text Clarity). Such findings confirm that the items included in each of the constructs are very closely related and assess the same variable. Convergent validity was determined by measuring the average variance extracted (AVE) for each construct. At that, AVE values are between 0.767 on Critical Thinking Prompts and 0.931 on Text Clarity, which are far above the 0.50 value recommended by Fornell and Larcker (1981). This implies that the indicators of each construct can be explained by more than half, which proves that the measurement items are converged on their latent constructs (Table 3).

Table 3. Cross Loadings

Constructs	Items	Loadings	CA	CR	AVE
Critical Thinking Prompts	CTP1	0.930	0.849	0.862	0.767
	CTP2	0.952			
	CTP3	0.920			
	CTP4	0.925			
policy framing	FU1	0.975	0.856	0.868	0.773
	FU2	0.968			
	FU3	0.986			
	FU4	0.968			
	FU5	0.970			
student understanding of fluoride science and policy	PF1	0.956	0.882	0.878	0.847
	PF2	0.944			
	PF3	0.917			
	PF4	0.942			
text clarity	TC1	0.974	0.975	0.982	0.931
	TC2	0.977			
	TC3	0.953			
	TC4	0.956			
visual support	VS1	0.963	0.944	0.960	0.857
	VS2	0.933			
	VS3	0.901			
	VS4	0.905			

Table 4. HTMT Matrix

	CTP	PF	FU	TC	VS
CTP	1				
PF	0.496	1			
FU	0.391	0.447	1		
TC	0.350	0.471	0.408	1	
VS	0.584	0.660	0.536	0.502	1

Table 5. Fornell-Larcker criterion

	CTP	PF	FU	TC	VS
CTP	0.932				
PF	0.473	0.940			
FU	0.381	0.435	0.973		
TC	0.336	0.456	0.401	0.965	
VS	0.552	0.629	0.518	0.482	0.926

Discriminant validity was estimated using two criteria that were complementary to each other: heterotrait-monotrait ratio of correlations (HTMT) and Fornell-Larcker criterion. The results of one of the assessments, the HTMT matrix, are presented in Table 4, where all the HTMT values are below the threshold of 0.85 (Zhang et al., 2025). For example, the HTMT between Critical Thinking Prompts and Visual Support is 0.584, and between Policy Framing and Student Understanding is 0.447, indicating that the sample points are distinct in terms of the construct.

Discriminant validity is further supported by the Fornell-Larcker criterion as shown in Table 5. Diagonal elements, square roots of AVE, vary between 0.926 (Visual Support) and 0.973 (Policy Framing), and each is larger than the inter-construct correlations in the off-diagonal positions. As an illustration, a square root of AVE (Student Understanding 0.940) is larger than the highest correlation involving Student Understanding and Visual Support (0.629). Likewise, the AVE square root (0.965) of Text Clarity is better than its correlations with other constructs (<0.482). This trend reassures the fact that every construct has a higher variance with its indicators compared to other constructs (Fornell & Larcker, 1981)

Structural Model

The overall model fit was good, with the leading indicators being within acceptable limits: $2/df = 1.79$, CFI = 0.963, TLI = 0.951, RMSEA = 0.053, and SRMR = 0.042, indicating a good fit of the proposed paths in

representing the data structure. Collectively, these findings provide evidence that all four input variables make a decisive contribution to understanding fluoride; however, Visual Support and Text Clarity appear to be high-potential change tools that enhance educational frontiers. In Table 6, there are the path coefficients, standard errors, t-statistics, and p-values of every direct effect.

The four direct paths to Fluoride Understanding were all statistically significant at $p < 0.01$, providing optimal validation of our expectations. The Critical Thinking Prompts display a positive relationship with Fluoride Understanding ($B = 0.098$, $t = 3.444$, $p = 0.001$), indicating that the mastery of fluoride-related policy and science is significantly enhanced by questions aimed at encouraging students to exercise their critical thinking (Table 6). Policy Framing also demonstrates a considerable, though not substantial, degree of contiguous effect on Fluoride Understanding (hiPhi 0.120, $t = 2.925$, $p = 0.003$), indicating that minor modifications in the presentation of policy data have a minor, yet discernible, impact on how students perceive the information. Text Clarity is more effective ($\beta = 0.164$, $t = 4.851$, $p < 0.001$), as the way of communication between the learner and the material should be easy to read and accurate. The most significant impact is that of Visual Support ($\beta = 0.309$, $t = 7.788$, $p < 0.001$), indicating that diagrams, charts, and other visual aids are most effective in increasing children's knowledge about fluoride science and policies.

Table 6. Path coefficients

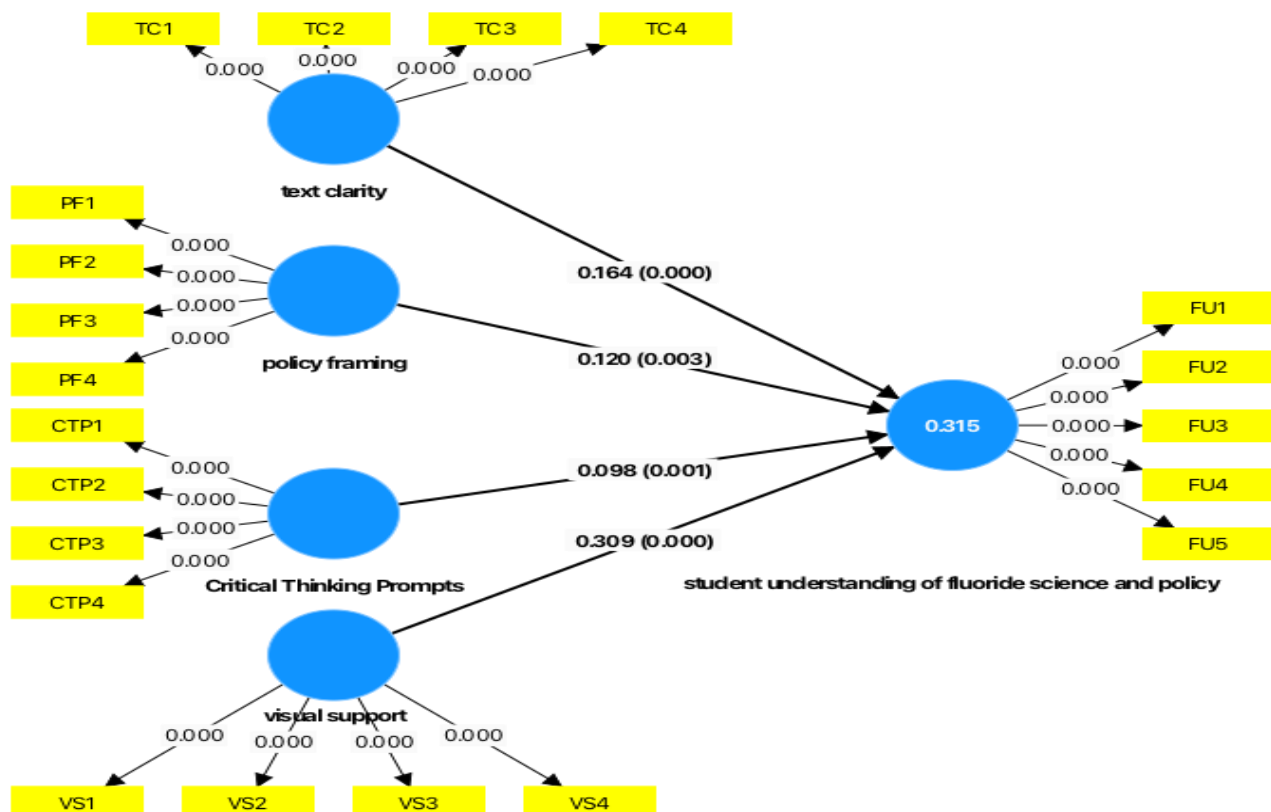
	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (O/STDEV)	P values
CTP -> FU	0.098	0.099	0.029	3.444	0.001
PF -> FU	0.120	0.121	0.041	2.925	0.003
TC -> FU	0.164	0.165	0.034	4.851	0.000
VS -> FU	0.309	0.308	0.040	7.788	0.000

The above relationships are visualized in Figure 1 below, which displays each standardized path weight as we annotate each arrow. This structural framework confirms our argument that a comprehensive system the blend of critical reasoning, intelligent policy messaging, plain texts, and concise use of graphics — most comprehensively and effectively develops children's understanding of fluoride science and the influence of public policies.

DISCUSSION

The results of the current study highlight the role of discourse design in shaping the bilingual nature of children in science- and policy-related fluoride education. Firstly, our quantitative data show that between the four variables, the influence of visual

support in overall fluoride understanding was the strongest (beta = 0.309, $t = 7.788$, $p < .001$), confirming the assertion by Dual-Coding Theory that aligned imagery and text generate complementary copies in memory (Woodside-Jiron, 2011). This was also reflected in qualitative feedback, in which students reported that infographics explaining water-treatment processes contributed to a situation in which things clicked, as a purely chemical description had left them feeling abstract. The clarity of the text also contributed significantly (beta = 0.164, $t = 4.851$, $p < .001$), eliminating the possibility of cognitive overload and helping learners grasp unfamiliar terms like mineralization without encountering jargon (Roguski & McBride-Henry, 2020). This evidence regarding the Cognition component of the C-A-C framework suggests that effective language and visual presentation help individuals process and build schemas.

**Figure 1.** Research Framework

Policy framing ($b = 0.120$, $t = 2.925$, $p = .003$), and critical-thinking prompts ($b = 0.098$, $t = 3.444$, $p = .001$), however, had a greater effect on their reported knowledge of the governance process involved in fluoride, including recognizing that local health boards establish fluoride standards, than on their understanding of the chemical action of the fluoride (Papadopoulos et al., 2014). Along these lines, the differential effects of science in decision-making settings and the questions posed to learners about who decides quality align with both the Framing Theory and the Theory of Transformative Learning. The use of such expressions will trigger the C-A-C model since it involves interest and perception of relevance, and thus motivates learning more (Bharwani et al., 2023).

In addition, the interaction effects, in which levels of clarity and vivid visuals, policy context, and critical prompts were paired with each other, resulted in synergistic effects at both cognitive and civic levels, implying that the interactions between the levels are greater than the sum of the individual levels. At this integrative synergy level lies successful Conation; here, students, in addition to recording a high level of factual knowledge, also demonstrated greater readiness to be involved in future community forums or school water-safety committees (Marsh-Richard et al., 2009).

These quantitative patterns were supported by qualitative observations, which showed that classrooms with elaborate flowcharts (accompanied by illustrations) and reflection questions were associated with more vibrant pupil discussions. Additionally, children in policy-framed groups were more keen to volunteer responses on municipal water boards (Arthur-Kelly et al., 2009; Bharwani et al., 2023). Sustained curiosity was also observed, as reported by teachers: students who accessed the critical prompts continued to ask questions of why and how days after the lesson.

Altogether, our findings confirm the hypothesis that the combined, discourse-based strategy is an optimal method for fostering scientifically literate and civically empowered learners, incorporating text clarity, imagery, policy framing, and critical thinking. This study, by directly associating every instructional methodology with objective gains in cognitive, affective and conative levels, presents a firm and statistically supported grasp of guidelines to the curriculum designer who, in response to the practical problems of our time, must find ways to promote not only understanding of the field of fluoride science, but also of informed participation in civic life.

THEORETICAL IMPLICATION

The study's contribution to discourse and education theory is the empirical demonstration of how selected instructional techniques relate to the CAC framework in

a public health context. First, our results confirm Dual-Coding Theory and Cognitive Load Theory, as they demonstrate that matching visual support and simplifying text clarity facilitate cognitive processing of complex scientific and policy texts to a large extent. Second, the distinct effects of policy framing and critical-thinking prompts demonstrate the transportation of Framing Theory and Transformative Learning Theory into the K-12 health education environment, as young learners are found to be able to understand government procedures after policy discourse places scientific evidence into the context of political decision-making. Lastly, the synergistic effect between the success of all four approaches suggests a comprehensive model of a discourse ecology, where the elements of cognitive ease, emotional appeal, and motivational appeal are integrated due to highly intertwined language selection, imagery, and questions. Such a joined model complements theoretical explanations of how discourse not only preconditions knowledge but also drives the affective investment and conative agency in readers of elementary age.

PRACTICAL IMPLICATIONS

Our findings provide practical advice to anyone who designs curriculum and health educators. They ought to be composed in the third-grade reading level most comprehensively, along with short sentences, familiar words, and definitions of extra words on the page. The provided text should be tightly coordinated with diagrams, flowcharts, and infographics to leverage the dual-coding advantages, particularly in demonstrating abstract processes such as fluoride adsorption or the flow of policy decisions. Classroom educators can sequentially present the following elements: clarified text, paired images, policy, and Socratic questions, to maximize fact retention as well as civic response. Lastly, community outreach and educational efforts driven by school districts and local- and state-based public-health agencies must seek to formally incorporate these discourse-levelling information into existing school curricula both in science and social-studies classes to ensure that future generations of citizens are not just informed about the importance of fluoride but made empowerment players in ensuring the safety of the water in their respective communities.

LIMITATIONS AND FUTURE RESEARCH

First, the research employs self-reported Likert-scale measures of scientific and civic knowledge, which can be influenced by the social-desirability bias and may not accurately represent actual knowledge or skill. Two, the sample population may be only representative of students in fourth to sixth grade in a single high-fluoride province. Thus, the generalization of the results to other age groups, different regions

with varying forms of culture or language dissimilarities, or other areas with minimal exposure to fluoride cannot be applied in the last instance. In contrast, the fully factorial design disentangles the main and interaction effects of four discourse strategies; other seemingly likely-to-have impacts, such as teacher facilitation style, peer collaboration dynamics, home-environmental reinforcement, or factors that moderate and mediate the way learning outcomes are achieved, are not captured.

FUTURE RECOMMENDATIONS

Future research in these areas will require that objective measures be included in assessing self-reports of self-education in fluoride science and policy appreciation, such as quizzes, performance tasks, or observational checklists. Longitudinal designs are necessary to determine the maintenance of knowledge, changes in civic attitudes, as well as real-life practices such as student engagement in school or community water-safety programs. Increasing the sample by varying geography and culture (rural and urban, different language groups, and various risk levels of fluoride) will also test the effectiveness and transfer of discourse-strategy effects. Lastly, integrating these optimized materials into service-learning or project-based modules, in which students can apply their learning to local water policy simulations or advocacy activities, would provide a dramatic test of the materials' ability to scale up cognitive and affective gains into conative performance.

CONCLUSION

To sum up, the current study provides a thorough factorial assessment of four key discourse strategies: text clarity, policy framing, critical-thinking prompts, and visual support, in the context of elementary fluoride education. These results show that simplification of words and parallelism of images have a significant effect on the improvement of scientific knowledge. In contrast, explicit practical circumstances and probing questions facilitate the development of civic understanding. Moreover, the synergistic interactional manner of all four strategies creates not only cognitive but also affective interaction and conative motivation, which is evident in the willingness of students to engage in mediating water-safety issues. Such awareness provides excellent direction to curriculum designers, teachers, and health organizations dedicated to fostering scientifically literate and civically empowered generations that can make informed decisions about community water safety.

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