

Research Article

Conception and Application of Biosafety Strategies in Daily Life for Preventing Communicable Diseases among Senior Secondary Students: A Cross-Sectional KAP Study in Dehradun District

Sukla Sinha¹, Geetu Gupta², Lalit Sachan³, Himanshu Tolani⁴

^{1,2}School of Education, Jigyasa University, Formerly Himgiri ZEE University, Dehradun, Uttarakhand, India

³Centre for AI, University of Petroleum and Energy Studies, Dehradun, Uttarakhand, India

⁴School of Health Science and Technology, University of Petroleum and Energy Studies, Dehradun, Uttarakhand, India

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I N F O

Corresponding Author:

Sukla Sinha, School of Education, Jigyasa University, Formerly Himgiri ZEE University, Dehradun, Uttarakhand, India

E-mail Id:

suklasinha1988@gmail.com

Orcid Id:

<https://orcid.org/0000-0001-6501-5658>

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A B S T R A C T

Background and Objective: The COVID-19 pandemic expanded biosafety beyond laboratory settings and highlighted its importance in routine life for preventing communicable diseases. As adolescents develop greater responsibility for their own health practices, this study assessed senior secondary students' knowledge, attitudes, and practices (KAP) regarding daily-life biosafety preventive strategies to promote biosafety as an essential life skill.

Methods: A cross-sectional descriptive survey design was used, with a validated, structured questionnaire with 58 items covering hygiene; infection control measures for communicable diseases, including zoonotic and vector-borne diseases; food and water safety; and safe waste management and environmental hygiene. Pearson and Spearman correlations, Welch's t-tests, and multivariable regressions were calculated through Python software (3.13.9).

Results: Students presented moderate knowledge (62.74%, mean 14.03, SD = 3.42), high attitudes (82.14%, mean 54.26, SD = 6.28), and stronger practices (56.31%, mean 84.17, SD = 11.92) regarding biosafety. Across KAP domains, female, urban, science, and private school students significantly outperformed their counterparts. A weak but positive correlation was detected among knowledge-attitude ($r = 0.470$), attitude-practice ($r = 0.429$) and knowledge-practice ($r = 0.275$). Regression analysis identified attitude as the primary predictor of practice ($\beta = 0.66$, $p < 0.001$), followed by knowledge ($\beta = 0.32$, $p = 0.012$).

Conclusion: The KAP pattern of moderate knowledge score, high attitude, and practice implied the externally driven habit formation and high motivation among adolescents. A weak yet positive association was found between conceptual knowledge, attitude, and application. The integration of cognitive, motivational, and contextual factors was

essential for school-based interventions and to form behavioural practices.

Keywords: Students, Health Education, Biosafety, Knowledge-Attitude-Practice, Communicable Disease, Disease Transmission, Public Health

Introduction

Biosafety traditionally refers to preventing unintentional exposure to biological agents and toxins or their accidental release into the environment.¹ “Thinking outside the box”² in a broader public health context, especially in the post-pandemic era, biosafety also encompasses the everyday preventive practices that individuals adopt to reduce the risk of infectious disease transmission. In this study, biosafety is conceptualized from a World Health Organization (WHO) One Health perspective,³ which recognizes the interdependence of human, animal, and environmental health and emphasizes preventive actions that reduce exposure to biological hazards and interrupt pathways of disease transmission. Accordingly, biosafety preventive principles encompass personal hygiene and sanitation, infection prevention and control, food and water safety, safe waste management, environmental cleanliness, and awareness of the interconnected health risks operating at the human–animal–environment interface. These domains collectively constitute a coherent biosafety framework because they share a common preventive objective: minimizing biological risk and promoting health protection across individual, community, and environmental settings. Therefore, biosafety preventive principles are conceptualized not as a collection of unrelated behaviors but as a unified framework of risk-reduction practices operating across multiple contexts of daily life.

The health and medical sciences research trend has accepted a multidisciplinary approach to health literacy. Seidl et al.⁴ have mentioned that a conclusive theoretical framework regarding adolescent health literacy is absent due to a focus on adults. In the case of children and adolescents, healthier behaviors are directly related to higher health literacy and to overall better health outcomes. Although baseline knowledge about preventive measures among adolescents exists but there are gaps regarding procedural and applied aspects (e.g., hygiene practices, disease prevention behaviors) related to various inconsistencies including behavioral tendencies and contextual constraints.^{5,6} It was during the COVID-19 pandemic that these deficiencies were thrust into the limelight and there was a clear dissonance between knowledge and practice. This calls for organized educational and behavioral interventions to improve biosafety literacy.⁷ Generally, adolescence as a formative period where lifetime beliefs and behaviors about health often crystallize;⁸ biosafety literacy during this phase is important for its long-term effects on overall public health

outcomes.^{6,9} Students in the penultimate classes of school education (Classes XI and XII) are considered to hold an independent outlook and sense of responsibility regarding their health behaviors. They are the emerging stakeholders of society.¹⁰ So, assessing their knowledge, attitudes, and practices (KAP) in school settings is important for reducing transmission of infections and increasing public health awareness.

According to Ratnaprabha G.K. et al. (2018)¹¹, girls demonstrated superior personal hygiene practices compared to boys in rural Karnataka, and maternal education and awareness of hygiene-related diseases were closely linked to improved outcomes. Socio-demographic characteristics, institutional context, and family economy are the influencing variables to measure awareness and KAP related to waste management, water, sanitation, and hygiene.^{12,13} Urban schools surpassed rural schools in sanitation infrastructure, waste management systems, and toilet adequacy, and though there are clear national guidelines, rural schools frequently lag.¹⁴ Environmental conditions like access to handwashing and sanitation have a direct impact on hygiene behaviors among school-going children in different cities of India.¹⁵ As per Devi et al. (2025)¹⁶, a gap between knowledge and actual hygiene behavior among primary school children in Assam pointed out that awareness alone did not consistently translate into practice. International literature involving school-to-college populations also mentions the same knowledge-behaviour gap. High levels of knowledge and positive attitudes do not necessarily lead to appropriate hygienic and preventive behaviours.¹⁷ The domains of environmental sanitation, food safety, and infectious disease show prevalent inconsistencies in behaviour. Behavioral outcomes depend on conceptual restrictions, infrastructural barriers, and socio-demographic variables.^{11,18,19} According to the literature review, the behavior of biosafety behaviour is developed through a complex interaction of cognitive, behavioral, and contextual factors rather than knowledge alone. It points out a significant limitation in transforming concepts and awareness into sustained practices.

The Health Belief Model (HBM) isolates an individual’s internal cognitive calculus regarding disease prevention.²⁰ In a decentralized community biosafety framework, a person’s compliance relies heavily on perceived susceptibility and perceived severity. When individuals view public health threats as both highly probable and acutely severe, their internal motivation to adopt preventive behaviors rises significantly. While the HBM maps internal risk perception, the Theory of Planned Behavior (TPB) explains the social and environmental forces that convert those perceptions into actual behavior.²¹ KAP survey, common in public health research, is appealing owing to its simplicity in design, quantification of the collected data, interpretability, and

succinct presentation of the results. It includes cognitive, affective, and behavioural domains.^{22,23} The knowledge domain captures conceptual understanding, attitude records perceptions and motivations, and practice represents observable behavior.^{24,25} These domains imply interrelationship, and attitude was supposed to channel knowledge into behavior.²⁶

The present study adopted this KAP framework. Here, the knowledge domain reflected individual-level conceptual understanding termed as conception, and the practice domain reflected the application of these concepts in routine life situations. It aimed to foreground the cognitive-behavioral continuum in biosafety preventive principles to curb the transmission of communicable diseases. Conception embodied the internal understanding that shaped risk perception, whereas application captured the translation of this understanding into daily-life practices within social and environmental contexts^{22,27} with the relevance of attitude as a determinant of behavioural outcomes.

Many KAP surveys have been conducted in school settings involving primary and secondary students on domains like water safety, sanitation, hygiene, food safety, environmental hygiene, and infection prevention separately. This KAP study tries to work on senior secondary students by combining such domains from a microbiological safety perspective akin to biosafety. It aimed to investigate the conception, attitudes application of biosafety in daily life among senior secondary students of Dehradun district, India, and to identify gaps across domains and generate evidence to inform educational and public health interventions targeting adolescent populations. The investigation was guided by hypotheses positing that higher biosafety knowledge will be associated with more positive attitudes and safer practices, with positive attitudes further promoting safer behavioral application. Additionally, it tried to examine whether knowledge, attitudes, and practices vary across demographic and academic factors such as gender, academic stream, school type, and region. Finally, it attempted to assess whether knowledge and attitude significantly predict biosafety practices, thereby identifying key drivers of biosafety engagement among students.

Material and Method

Study design

A cross-sectional descriptive survey²⁸ was conducted among senior secondary school students (Classes XI and XII) in Dehradun district, Uttarakhand, India.

Sampling Technique

The researcher used a multistage sampling method to secure geographic and sociodemographic diversity. As per 2024-2025 CBSE SARAS data, Dehradun district had 187 CBSE

co-educational schools, of which 102 (54.5%) schools were urban, 85 schools (45.5%) were rural while 157 (84%) schools were private and 30 (16.0%) were government. In the first stage, school selection was based on distribution-informed purposive sampling. Thus, the selection of 15 schools was informed by the existing structure of the sampling frame, rather than by equal allocation across school categories. Out of these 15 schools, 8 (53.3%) were located in urban areas and 7 (46.7%) in rural areas. By school sector, 12 (80.0%) were private schools, and 3 (20.0%) were government schools. The selected schools were intended to provide coverage of the principal school contexts relevant to the study. The rationale to choose purposive sampling technique included practical and institutional constraints encountered during school recruitment such as administrative and logistic feasibility, accessibility, and willingness to participate. In the second stage, inclusion and exclusion criteria were applied to set the eligibility of the student respondents within selected schools. Respondents were randomly selected based on the gender and academic stream, targeting balanced totals for male/female (420/420) and science/non-science (420/420). All the schools had visible basic safety compliance like water filtration system, running water, handwashing station, dustbins, and clean dining places, etc. Students from classes XI and XII were chosen from both private institutions and Atal Utkrisht Government Inter Colleges from urban and rural settings using proportionate simple random sampling. Based on an assumed prevalence of 50%, 5% precision, and a 95% confidence level, the sample size was adjusted for a 1.5 design effect and a 10% non-response rate. The final cleaned sample reached to 840. The adequacy of the samples had enough statistical power for subgroup analyses. Stratification ensured that key institutional characteristics were represented, while classroom-based inclusion reduced systematic exclusion of eligible participants.

Sample Size Determination

The sample size for the present study was determined using Cochran's formula for large or infinite populations, which is widely applied in public health and educational research.²⁹ The formula is expressed as: $n_0 = Z^2pq / e^2$, where n_0 = initial sample size, Z = standard normal deviate corresponding to the desired confidence level (1.96 for 95%), p = estimated proportion of the population possessing the attribute of interest, $q = 1 - p$, e = margin of error. As no previous estimates of the awareness of biosafety among senior secondary students were available, the proportion (p) was taken as 0.5 because this would produce the maximum sample size and hence increase the power of the study. Substituting the values $1.96 \times 1.96 \times 0.5 \times 0.5 / 0.05 \times 0.05 = 385$. The calculation showed that at least 385 participants were needed to obtain a confidence level of

95% with a margin of error of $\pm 5\%$. A total of 840 students were finally selected as the sample size to maximize the subgroup statistical strength and to minimize the margin of error to about 3.38% at the same confidence level.

Tool of the Study

A structured, pretested questionnaire³⁰ based on standard KAP frameworks for measuring biosafety KAP in daily life was administered in classrooms. Face and content validity were evaluated by 11 subject experts. Later, a pilot study with 290 senior secondary students was conducted to test the reliability and construct validity. Exploratory factor analysis established construct validity, while KR-20 and Cronbach's α determined internal consistency, ensuring the questionnaire's robustness for educational and public health applications. The content validity, construct validity and internal consistency were projected with S-CVR = 0.79 and S-CVI = 0.96, KR-20 = 0.6062 for knowledge, Cronbach's α = 0.7426 for attitude and Cronbach's α = 0.8060 for practice. Exploratory factor analysis converged into 4 factors. Questionnaire on Biosafety and its Application in Daily Life (BADL) is a qualitatively and quantitatively validated questionnaire with a good level of reliability.³¹ The instrument was divided into knowledge (23 binary items), attitude (13 Likert-scale statements), and practice (22 Likert-scale items) domains. Demographic variables consisted of class (XI/XII), gender, academic stream, school type, and region.

Inclusion and Exclusion Criteria

Senior secondary students who agreed to take part voluntarily and who were able to understand and respond to the study questionnaire were included. Students unwilling to participate and those who submitted incomplete questionnaires were methodically not included.

Data Collection Procedure

Data collection was conducted at selected schools during school hours in an organized classroom environment. Prior permission for accessing the chosen schools was sought through email and telephonic communication from the school authorities. All the participating students were briefed about the objectives of the study, voluntary participation, and details regarding the instrument of measurement. After guaranteeing confidentiality, questionnaires were distributed during the leisure period, and filled forms were retrieved systematically.

Statistical Analysis

Statistical calculations were performed using Python software version 3.13.9. Data preprocessing and coding were conducted using the pandas library, while numerical computations were performed with NumPy. Inferential

analyses, including t-tests, correlation, and regression modelling, were performed using SciPy and statsmodels. All analyses were reproducible through scripted workflows applied to the primary dataset. A complete-case analysis was conducted because the dataset was 100% complete with no missing data (0.00% missingness) across all variables. Associations between the main domains of KAP were tested using Pearson's product-moment correlation (r) and Spearman's rank correlation (ρ) coefficients. A non-parametric robustness check was performed by calculating Spearman's coefficient to account for possible deviations from normality. Categorical variables (gender, stream, school type and region) were dummy-coded, with Male, Non-Science, Government (GOVT) and Rural as reference categories, respectively. Potential heteroscedasticity was addressed by applying heteroscedasticity-robust standard errors (HC3 estimator). The Variance Inflation Factor (VIF) was used to test Multi-collinearity. To account for possible unequal variances, Welch's t-test was applied for differences between subgroups. The practical significance of subgroup differences was reported as standardized effect sizes (Cohen's d) and corresponding 95% confidence intervals (CI).

Scoring

Knowledge scores were determined by the total number of correct responses, ranging from 0 to 23. Attitude and practice scores were calculated by totaling the 5-point Likert scale values, where higher totals indicated more positive attitudes and superior practices. Both sections utilized a 5-to-1 scoring sequence: the attitude domain ranged from Strongly Agree having 5 points to Strongly Disagree having 1 point, while the practice domain followed the same pattern from Always to Never. There were some items in those sections which were scored reversely. Modified Bloom's cut-off³² was used to group KAP scores into High (75–100% of total score), Medium (60–75%), and Low (<50%) categories.

Results

Sample Characteristics

The dataset included 840 students with an equal distribution of 420 males (50.0%) and 420 females (50.0%) participants. While 422 students were from rural areas (50.24%), 418 were from urban (49.76%) areas, which indicates a balanced representation of both regions. Most students belonged to private schools 604 (71.9%), while 236 (28.1%) attended government schools as 80% of the total schools were private. Both science and non-science stream students were equal in number, 420 (50.0%) each. Overall, the sample was well balanced by gender, stream, and region, with greater representation from private schools.

Summary of KAP Scores

Knowledge scores fell within the range of 3 to 23, most students scored between 11 and 17, with a peak at 14 (Table 1; Fig. 1). Attitude scores ranged from 23 to 65 (theoretical range: 13–65), a left-skewed distribution concentrated between 51 and 59 (Table 1; Fig. 2). Practice scores ranged from 47 to 110 (theoretical range: 22–110), indicating moderate variability, and most scores falling between 76 and 93 (Table 1; Fig. 3). The central tendency and variability of the KAP scores are presented in Table 1. The distribution of knowledge scores with a mean of 14.03 (median of 14, SD = 3.42) showed that slightly more than half of the students answered the biosafety concept items correctly. Attitude scores with a mean of 54.26 (median of 55, SD = 6.28) reflected a strong perception of preventive health behaviours. Practice scores with a mean of 84.17 (median of 85, SD = 11.92) put forward that a considerable proportion of students reported relatively safe biosafety-compliant behaviours, even as individual variability remains

discernible. This pattern could plausibly be a reflection of increased exposure to biosafety-related communication during and after the COVID-19 pandemic, reinforcement through school-based awareness and drive programs, and influences from family and the wider social environment. But these factors were not directly assessed in the present cross-sectional study.

A large proportion of students (62.74%) had medium level of knowledge. A smaller percentage (10.95%) in the high level and a significant percentage (26.31%) in the low level were focused on gaps in conceptual understanding. The students had a very positive attitude towards biosafety. A large majority (82.14%) fell into the high category, and a very small number (0.24%) into the low category. Good biosafety practices were shown by students. More than half of the students (56.31%) were in the high levels and a considerable number were in the moderate level (43.21%). The students have favorable attitudes and good practices, but inadequate knowledge (Table 2).

Table 1. Summary Statistics for KAP Scores

Domain	Mean	SD	Median	Min	Max	IQR
Knowledge	14.03	3.42	14.00	3	23	12–16
Attitude	54.26	6.28	55.00	23	65	51–59
Practice	84.17	11.92	85.00	47	110	76–93

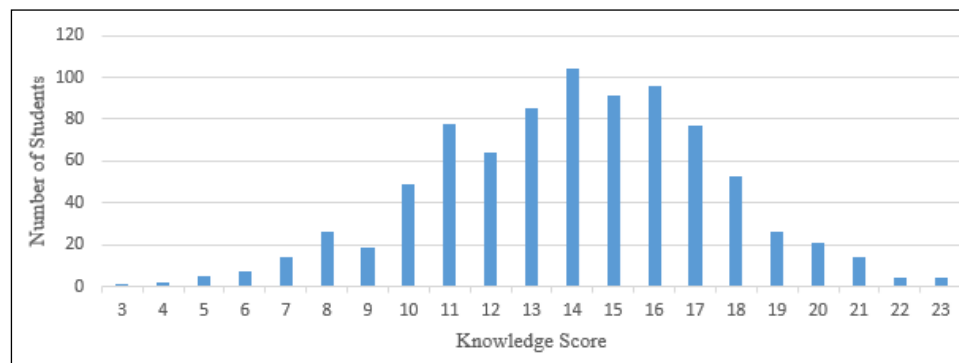


Figure 1. Distribution of Knowledge Scores among Students

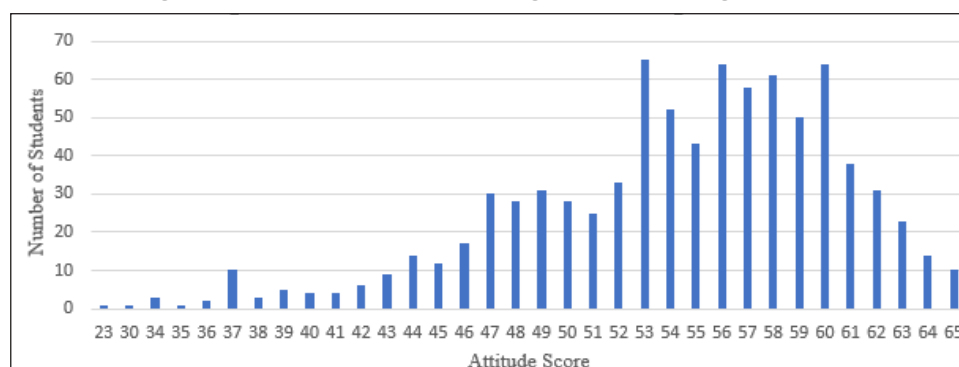


Figure 2. Distribution of Attitude Scores among Students

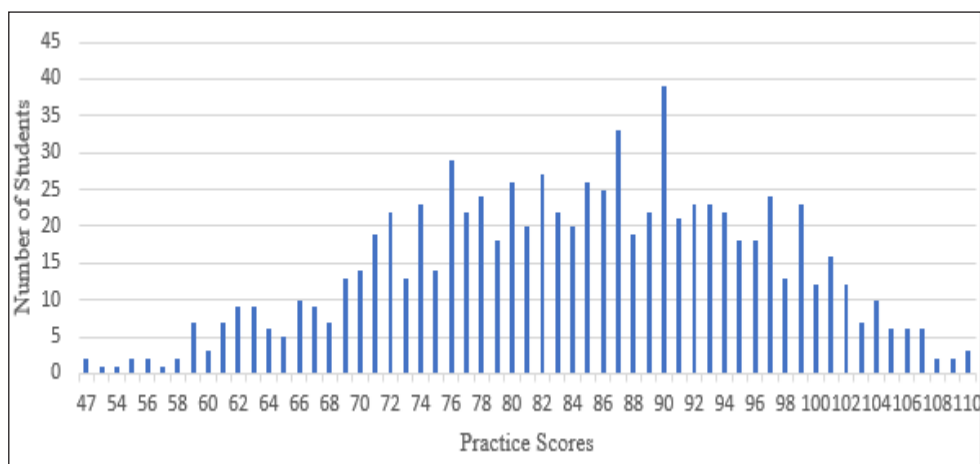


Figure 3. Distribution of Practice Scores among Students

Table 2. Knowledge, Attitude, Practice, Frequency, and Percentage

Knowledge Level	Count	Percentage
Low	221	26.31%
Medium	527	62.74%
High	92	10.95%
Attitude Level		
Low	2	0.24%
Medium	148	17.62%
High	690	82.14%
Practice Level		
Low	4	0.48%
Medium	363	43.21%
High	473	56.31%

Comparison of KAP Scores across Demographic Variables

To find out the significant difference among all subgroups Welch's two-sample t-tests, group mean differences, degree of freedom (df), Cohen's d with 95% CI (lower, upper) were calculated across three domain scores (Table 3). All domains showed statistically significant gender differences. Female students scored higher than males in knowledge (14.27 / 13.79, $t=2.0535$, $df=821.6$, Cohen's $d=0.1417$, 95% CI= [0.0063,0.2771]), attitude (55.43 / 53.09, $t=5.4780$, $df=785.3$, 95% CI=0.3780 [0.2416,0.5145]), and practice (87.29 / 81.03, $t=7.9237$, $df=824.5$, 95% CI=0.5468 [0.4090,0.6845]), indicating overall stronger biosafety knowledge, more positive attitudes, and safer practices among female students compared to male counterparts. No significant differences were found between government and private school students in attitude scores (54.09 / 54.68, $t=-1.1881$, $df=413.5$, 95% CI=-0.0929 [-0.2434,0.0576]), and practice scores (84.23 / 83.98, $t=0.2998$, $df=516.9$, 95% CI=0.0212 [-0.1293,0.1716]). However, knowledge scores

(14.22 / 13.55, $t=2.3202$, $df=360.5$, Cohen's $d=0.1955$, 95% CI= 0.1955 [0.0448,0.3463]) were significantly higher among private school students (Table 3). Science students scored higher in knowledge (15.17 / 12.89, $t=10.2191$, $df=836.8$, 95% CI=0.7052 [0.5658,0.8446]), attitude (55.65 / 52.86, $t=6.5893$, $df=796.5$, 95% CI=0.4547 [0.3177,0.5917]), and practice (85.46 / 82.86, $t=3.1900$, $df=837.6$, 95% CI=0.2201 [0.0845,0.3558]) than non-science students. Science students demonstrated stronger biosafety knowledge, more favorable attitudes, and safer practices probably due to greater curricular exposure to scientific knowledge (Table 3). The regional comparison revealed statistically significant differences between urban and rural students, and urban students scored better in knowledge (14.32 / 13.75, $t=2.4212$, $df=837.9$, 95% CI=0.1671 [0.0316,0.3026]), attitude (55.09 / 53.44, $t=3.8326$, $df= 824.7$, 95% CI=0.2643 [0.1285,0.4002]), and practice scores (85.14 / 83.19, $t=2.3801$, $df=834.6$, 95% CI=0.1642 [0.0287,0.2997]). This suggests that urban students had better access to educational resources or exposure to health-related information, and

were more favorably oriented toward maintaining safe health and hygiene practices. Overall, school's location played a significant role in shaping biosafety awareness and behavior (Table 3).

Normality was tested using the Shapiro-Wilk test. While some subgroup scores significantly deviated from normality (e.g., Attitude in private schools: $W = 0.9524$, $p < 0.001$), parametric Welch's t-tests were used due to the large sample size ($N = 840$ overall, with all subgroup sizes $N \geq 236$), which invokes the Central Limit Theorem. To record potential heteroscedasticity, Welch's t-test (which does not assume equal variances) was used. Levene's test confirmed significant variance heterogeneity in several cases, such as Attitude by Gender ($W = 20.6542$, $p < 0.001$) and Practice by School Type ($W = 15.8412$, $p < 0.001$), justifying the Welch adjustment. Cohen's d was added with its 95% Confidence Interval (CI) for all subgroup comparisons to report practical significance alongside p-values.

Correlation across KAP

Pearson's correlation and Spearman's rank correlation coefficients determined the relationships among the KAP

domains and gauged the magnitude and direction of their associations (Table 4).

Correlations were weakly positive across all KAP domains. Knowledge-attitude (Pearson $r = 0.4699$; Spearman $\rho = 0.4387$; $p < 0.001$), knowledge-practice ($r = 0.2773$; $p = 0.2743$; $p < 0.001$), and attitude-practice ($r = 0.4285$; $p = 0.3989$; $p < 0.001$) showed a significant relationship. With rising knowledge levels, attitudes became more favorable, and practices correspondingly safer. All three domains were closely interwoven. Gains in knowledge and attitudes are likely to be translated into improved biosafety practices. The associations supported the conceptual framework of the KAP continuum. The close alignment between Pearson and Spearman coefficients across all variables (e.g., Knowledge-Attitude: Pearson $r = 0.470$ vs. Spearman $\rho = 0.439$; Attitude-Practice: Pearson $r = 0.429$ vs. Spearman $\rho = 0.399$; Knowledge-Practice: Pearson $r = 0.275$ vs. Spearman $\rho = 0.272$) demonstrated that the identified relationships are robust and not driven by outliers or specific distribution assumptions.

Table 3. T-test and Cohen's d Subgroup Comparisons

Score Domain	Comparison (Group 1 vs 2)	Means (G1 / G2)	Welch's t	df	Cohen's d [95% CI]
Knowledge	Private vs Government	14.22 / 13.55	2.3202	360.5	0.1955 [0.0448,0.3463]
	Female vs Male	14.27 / 13.79	2.0535	821.6	0.1417 [0.0063,0.2771]
	Science vs Non-Science	15.17 / 12.89	10.2191	836.8	0.7052 [0.5658,0.8446]
	Urban vs Ru- ral	14.32 / 13.75	2.4212	837.9	0.1671 [0.0316,0.3026]
Attitude	Private vs Government	54.09 / 54.68	-1.1881	413.5	-0.0929 [-0.2434,0.0576]
	Female vs Male	55.43 / 53.09	5.4780	785.3	0.3780 [0.2416,0.5145]
	Science vs Non-Science	55.65 / 52.86	6.5893	796.5	0.4547 [0.3177,0.5917]
	Urban vs Ru- ral	55.09 / 53.44	3.8326	824.7	0.2643 [0.1285,0.4002]
Practice	Private vs Government	84.23 / 83.98	0.2998	516.9	0.0212 [-0.1293,0.1716]
	Female vs Male	87.29 / 81.03	7.9237	824.5	0.5468 [0.4090,0.6845]
	Science vs Non-Science	85.46 / 82.86	3.1900	837.6	0.2201 [0.0845,0.3558]
	Urban vs Ru- ral	85.14 / 83.19	2.3801	834.6	0.1642 [0.0287,0.2997]

Table 4. Pearson and Spearman Correlations (N = 840)

Correlation Pair	Pearson r [95% CI]	Pearson p-value	Spearman p [p- value]
Knowledge & Attitude	0.4699 [0.4154,0.5209]	< 0.001 (2.38×10 ⁻⁴⁷)	0.4387 (1.45 × 10 ⁻⁴¹)
Attitude & Practice	0.4285 [0.3717,0.4822]	< 0.001 (7.63×10 ⁻³⁹)	0.3989 (1.97 × 10 ⁻³³)
Knowledge & Practice	0.2773 [0.2136,0.3386]	< 0.001 (2.72×10 ⁻¹⁶)	0.2743 (5.82 × 10 ⁻¹⁶)

Multivariable Linear Regression Predicting Practice Scores

A multivariable linear regression model (Table 5) precisely delineated independent predictors of biosafety practices among student participants. The model incorporated knowledge score, attitude score, gender, region, academic stream, and school type as predictors. The estimated model was: Practice Score = $\beta_0 + \beta_1(\text{Knowledge}) + \beta_2(\text{Attitude}) + \beta_3(\text{Gender}) + \beta_4(\text{Region}) + \beta_5(\text{Stream}) + \beta_6(\text{School Type})$.

The regression model was statistically significant ($p < 0.001$) with the predictors interpreting a decent portion of the variability in the outcome ($R^2 = 0.229$). The model effectively explained a significant portion of the differences observed in biosafety scores across the included predictors. They were relevant drivers of biosafety behaviours rather than random noise. As attitude came out as the strongest and most influential predictor ($\beta = 0.66$; $p < 0.001$), it can be explained that positive perceptions of biosafety lead to consistent biosafety behaviours. Knowledge scores achieved statistical significance and a small but positive relation with practice ($\beta = 0.33$, $p = 0.013$). Higher levels of biosafety knowledge were interlinked with better-reported practices, although the magnitude was smaller than the attitude. Females displayed higher practice scores than males ($\beta = 4.68$, $p < 0.001$). While knowledge and attitudes contribute to biosafety practices, the reinforcement of behavioral orientation remains essential for promoting consistent

biosafety behaviour among students. Other demographic factors, including region, academic stream, and school type were not significant independent predictors of practice scores in this multivariable model.

The reference categories (baselines) were: Gender : Male (reference group: Female); Region : Rural (reference group: Urban); Stream : Non-Science (reference group: Science); School Type : Government (Govt.) (reference group: Private). The normality of the residuals of the main regression model (Table 5) was tested using the Jarque-Bera test (JB = 10.89, $p = 0.0043$) and the Shapiro-Wilk test ($W = 0.9940$, $p = 0.0021$). Skewness was very low (-0.279) and kurtosis was 2.986 (very close to the normal value of 3.00), although the values were statistically significant due to the large sample size, confirming that the assumption of residual normality is practically met. The Breusch-Pagan test was not significant (LM = 6.69, $p = .3505$) indicating homoscedasticity. The stability of the coefficients, t-statistics and significance levels was tested using an HC3 heteroscedasticity robust standard errors model as a robustness check. Variance Inflation Factor (VIF) was used to check the multi-collinearity. VIF for the predictors are: Gender (Female vs. Male): 1.057, Region (Urban vs. Rural): 1.036, Stream (Science vs. Non-Science): 1.136, School Type (Private vs. Government): 1.048, Knowledge Score (raw): 1.398, Attitude Score (raw): 1.350. All the values are well below the standard threshold of 5.0 indicating no multi-collinearity concerns.

Table 5. Multivariable Linear Regression: Non-Robust vs. Heteroscedasticity-Robust (HC3)

Predictor (β)	Coefficient (β)	Non-Robust SE	Robust SE (HC3)	Robust 95% CI	Beta
Intercept	40.56	3.25	3.08	[34.53, 46.59]	—
Knowledge Score (raw)	0.33	0.13	0.13	[0.09, 0.58]	0.0960
Attitude Score (raw)	0.66	0.07	0.07	[0.52, 0.79]	0.3472
Gender (Female)	4.68	0.74	0.76	[3.19, 6.16]	0.1970
Region (Urban)	0.38	0.74	0.74	[-1.06, 1.82]	0.0158
Stream (Science)	-0.07	0.77	0.77	[-1.57, 1.43]	-0.0029
School Type (Private)	1.16	0.82	0.80	[-0.40, 2.72]	0.0438

Model Fit: $R^2 = 0.229$, Adjusted $R^2 = 0.223$, N = 840. Dependent Variable: Raw Practice Score

Discussion

In the educational settings of Uttarakhand, this study presented critical insights into the conception and application of biosafety principles in daily life among senior secondary students of Dehradun district. According to the KAP scores analysis, the students possessed moderate knowledge, but comparatively stronger attitudes and practices. A moderate knowledge score indicated a partial understanding of underlying concepts, whereas application (practice) seemed comparatively robust. The results indicated a gap between conceptual grasp and behavioral expression, but it could not nullify the relationship between these two. The positive but weak correlation between knowledge and practice suggested that the increase in the conception could enhance application through behavioural outcomes and in the regression model knowledge came out as a significant predictor of behaviour. The pattern of medium knowledge, high attitude, and moderately high practice levels indicated externally driven biosafety compliance.

Girls secured significantly higher scores than boys across KAP domains. Females formed better conception and application of what they learned in health-related matters. These gendered characteristics were consistent across Asian countries. Girls also performed better than boys in hygiene-related knowledge and behaviors in Central Kazakhstan and India.^{11,33} Differences in academic stream hinted at the role of curricular exposure, with science students performing better across all three KAP domains.

Multivariable regression analyses established a more nuanced view of the interactions within KAP domains. Attitude became the primary predictor of practice. Gender was also a significant predictor. It outpaced knowledge, gender, region, and school type in terms of impact. These outcomes aligned the theoretical proposition that motivational and perceptual factors had more decisive impact on behavioral outcomes than cognitive awareness alone.^{26,34} Though causality cannot be established through cross-sectional studies, the results resonated behavioral mediation models in which attitudes operate as the critical conduit linking knowledge to action.³⁵ This model was useful in understanding biosafety as a behavioral construct, in which cognitive awareness must be reinforced by attitudinal orientation and contextual factors to achieve consistent application.

The relatively high scores seen among female, urban, and science-stream students explored the need of further study the impact of cognitive exposure and socio-behavioral dynamics. The observed effects of gender, region, academic stream, and school type on behavior indicated the importance of context beyond just knowledge. Considering the global evidences and the results of this study, it can be observed that biosafety behavior developed through

a complex interaction of conception, attitude, gender, educational exposure, and institutional environment. Global evidence also reinforced the role of broader socio-demographic and environmental factors in the same way of this study.^{17,19,36} This study specified that urban students got significantly higher scores than that of rural ones and private school students had greater knowledge than government counterparts.

In some Indian states, behavior-focused interventions were suggested due to breaches between awareness and action.^{12,16} The knowledge-practice gap in environmental sanitation and waste management was evident in studies from the Indian states of Uttarakhand and Himachal Pradesh.^{13,18} Children secured overall good scores across KAP domains related to COVID-19 and food safety. Their conceptual limitations and socio-demographic factors influenced their behavioral outcomes.¹⁹ Studies acknowledged that infrastructural limitations often constrained the development of strong hygiene behaviors.^{15,37} Even the most informed children lacked safety-compliant behaviours when they didn't have adequate facilities.³³ Institutional and contextual factors positively or negatively shape biosafety practices. Gender, academic stream, region, and school type were used in this study as the vital variables to find out these areas of concern previously studied.

Combining previous studies with this present study, it can be said that advancing adolescent biosafety behavior is not just the transmission of information. It calls for the need of skill-based training, habit formation, peer influence, and experiential learning that engage students beyond awareness. Adolescents should act as agents of change, setting in motion a ripple effect of behavioral transformation within communities.³⁸ A combined curriculum with knowledge input and habit formation from early life can nurture a culture of safety and foster a society that values a holistic approach to the environment and works together toward a peaceful and sustainable future. It shares the view of the WHO One Health framework and Sustainable Development Goals 3 and 4. By establishing everyday biosafety practices, good health and well-being, and quality education can be promoted to reduce health risk through preventive behavior and sustainable school-based health education.^{39,40}

Some of the key limitations of this study were its geographical limitations, a small sample size, locally sampled student population, and reliance on the subjective nature of self-reported data. While the purposive selection of schools limits strict statistical generalization, the relatively large sample size and inclusion of students from multiple institutions provide a broad cross-section of the target population. Future studies employing probability-based school selection across a broader sampling frame would strengthen the

external validity and generalizability of the findings. The results acted as a benchmark for comparative, longitudinal, and intervention-based studies at subsequent stages. These outcomes also provided an important reference range for future research to be conducted along similar lines, but with a larger scope for health education policy-making.

Conclusion

This current investigation tried to recast biosafety preventive strategies to stop transmission of biohazards and communicable diseases and as a daily-life health safety behavioral construct by operationalizing it through KAP continuum. The results presented a snapshot of the current situation of the students' KAP on the construct. Secondly, it furnished empirical evidence on the KAP inter-relationship and, notably, brought into focus attitude as the most influential predictor of behavior. Third, the pattern of moderate knowledge score, high attitude, and practice, opposed the established high knowledge and low practice pattern. It implied the externally driven habit formation and a high motivation among adolescents. It was relevant to public health education for identifying adolescents as pivotal agents in the diffusion of health behaviors within communities. Fourth, an association between conception, attitude, and application was found.

This research facilitated a greater understanding of the deficiencies, relationships, influential factors, and the current status of the KAP scores of senior secondary students in Dehradun district. It became imperative to create a perfect balance among conception, orientation, application, and contextual dimensions to establish a sustainable biosafety culture for strengthening broader public health preparedness and resilience. In future, comparative, interventional and action researches could be conducted to delve deep into specific demographic, curricular and environmental factors which can predict behavioural application more accurately to provide more information to policy making.

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