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KNOWLEDGE GAINS IN BIOMEDICAL WASTE MANAGEMENT FOLLOWING A SINGLE FOCUSED DIDACTIC LECTURE: A STANDARDIZED CROSS-SECTIONAL STUDY IN MEDICAL UNDERGRADUATES

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Abstract

Introduction:
Competency in Biomedical Waste Management (BMWM) is critical for institutional compliance and minimizing infection risk, aligning with national standards such as India's BMWM Rules, 2016. Despite this mandate, persistent knowledge gaps are prevalent among undergraduate medical students. This study aimed to quantify the immediate change in BMWM knowledge following a focused didactic lecture and identify specific areas of improvement.

Methodology:
A quasi-experimental single-group pre-test–post-test design was used with an enrolment of 73 3rd-year medical students. This intervention consisted of a Pre-test (17-item questionnaire) followed by a focused didactic lecture followed by a same given before lecture session.17-item questionnaire administered across five domains of practice: Waste Categorization; Colour-Coding; Disposal Methods; Regulatory Facts. Statistical analysis included paired t-tests and Cohen's d (effect size) by using SPSS software version: 25

Results:
The average knowledge increased widely, and it was highly significant. The mean score increased from 7.64±3.10 (44.9% accuracy) in the pre-test to 11.08±2.15 (65.2% accuracy) in the post-test. The overall mean improvement of 3.44 points gave a **Very Large Effect Size** (Cohen's d=1.46; p<0.001). The largest domain gain occurred for Waste Categorization (36.17% increase). By contrast, abstract Regulatory Facts knowledge did not significantly improve (p=0.619). While the improvement was impressive, only 16.4% of students achieved the professional competency threshold (≥80% score) on post-test, up from 5.5% on pre-test.

Conclusion:
A single focused didactic lecture can indeed have an effect for enhancing basic BMWM knowledge among medical students but it does not raise to the high level of mastery needed for safe clinical practice. The low final competency rate (83.6% failure to attain ≥80% score) underscores the need for a continuing education strategy that involves constant assessments of practical skills as well as experiential reinforcement, particularly addressing complex disposal procedures and regulatory compliance details.

Keywords: Biomedical waste, BMWM, Colour-coding, Medical Undergraduates, pretest-post-test.

Introduction

Background

India's Bio-Medical Waste Management (BMWM) Rules, 2016 - amended in 2018 and 2019 - have provided that colour-coded segregation, bar-coding/traceability, and regular training of personnel in healthcare facilities, including teaching hospitals, made mandatory. Biomedical Waste Management (BMWM) competency is essential for ensuring safe clinical service in hospitals, nevertheless there are deficiencies among many healthcare practitioners, hospital staff, and medical undergraduates. (1)

Rationale

Compliance with the Bio-Medical Waste Management (BMWM) Rules is a mandatory prerequisite for clinical safety and institutional compliance. Our analysis found that, even when an effective didactic intervention was applied (Cohen's d = 1.46), the competency of undergraduate students remained critically low at just 16.4 per cent after the training. The vast disparity between theoretical knowledge acquisition and demonstrated professional mastery serves as an important barrier to adherence, and this is a difficulty commonly observed in the many previous similar studies done on healthcare workers. It is thus urgently justified that a focused Knowledge, Attitude and Practice (KAP) study be undertaken to diagnose the behavioural, attitudinal, and operational impediments preventing knowledge translation into consistent and safe practice. (2)

Research gap

Despite having the legal background which was well established as per the Bio-Medical Waste Management Rules, 2016 and detailed operational guidelines issued by the Directorate General of Health Services and CPCB, however, undergraduate medical education continues to demonstrate critical deficiencies in knowledge and practice regarding biomedical waste management (BMWM). A significant gap still exists between the theoretical training provided and the ability to achieve operational compliance with BMWM standards that has been found in several national publications which are similar, which indicated poor transfer of understanding to practice and retention of regulatory knowledge by trainees. Yet, little is known about structured, long-range, skill-based training models which provide a systematic approach to promote continuous competence and compliance with BMWM systems in the clinical environment. Therefore, incorporating these forms of periodic formative assessment and experiential reinforcement in the curriculum is crucial in closing the knowledge - practice gap in biomedical waste management. (3)

Study objectives

This study's objective is to determine whether undergraduate medical students benefit from a focused didactic lecture on knowledge enhancement in Biomedical Waste Management (BMWM) in accordance with the Biomedical Waste Management Rules, 2016. The specific goals are: 1. to measure baseline knowledge in key functional areas of BMWM—waste categorization, color-coding, disposal, and regulatory facts – Primary objective; 2.1. to assess knowledge gains and domain-specific improvements after the intervention (Secondary Objective 1); 2.2. to identify remaining learning gaps, particularly in regulatory compliance areas (Secondary Objective 2); and 2.3. recommend pedagogical interventions that are consistent with the national BMWM guidelines for achieving sustainable competency in waste handling and infection prevention (Secondary Objective 3). (4)

Material and Methods

This Study protocol was reviewed and approved by Institutional Ethics Committee. All participants were briefed about the aim and procedures of the study. Informed consent in writing was obtained from each participant before data collection, by following the principles of the Declaration of Helsinki and relevant national ethical guidelines. Data collection was done after obtainment of Consent from participants. To get consent from every participant, we made a pre-formatted Consent form with specified information regarding our study, its criteria, and the role of participants and about potential consequences on indulging our study.

Study design - Quasi experimental pre-test followed by Didactic Lecture, then immediately post-test assessment. [(5)]

Study setting - The study was conducted during August 2018 in a tertiary-care teaching hospital (Department of Pharmacology), Gayathri Vidya Parishad Medical College, Visakhapatnam, using existing undergraduate teaching infrastructure and hospital waste-management facilities. Participants were 3rd-year MBBS students enrolled at the institution; the matched cohort used for analysis comprised N = 73 students who completed both pre- and post-tests. [(6)]
The teaching process took place in a standard lecture hall and a focused didactic lecture on Biomedical Waste Management (BMWM) was organised; the assessments (paper-based 17-item questionnaire) were administered immediately before and after the session. Material for practical/operational reference and scoring rubrics were aligned with the CPCB/DGHS BMWM Rules, 2016 and the Directorate's implementation guidelines to ensure content validity of items. [(7)]

Participant enrolment and sample-size calculation
Participants were recruited from the 3rd-year MBBS class. Most of the previous similar studies has included sample population by random sampling, purposive sampling, and multiphase clustered sampling. But in this study, we are not randomizing only using a whole single MBBS batch of 3rd year, because they have Biomedical Waste Management in their syllabus as a part of Social and Preventive Medicine subject. In the initial phase of the study, whole single batch of MBBS students were included, but after rectifying data according to matching and proper demographic and identification criteria, most of the students were eliminated, due to the above issues like matching of pre-test results with post-test results due to lack of registration number in the form also some students failed to fill pre-test and some are failed to fill post-test and also improper filling. The matched analytical cohort in the present study comprised only **N = 73** students who completed both pre- and post-tests. Sample-size justification and calculations follow.

Sample-size formula for paired (pre–post) mean difference
Use the standard formula for a paired t-test (detecting a mean change Δ in paired scores):
$N = (Z_{\alpha/2}+Z_{\beta})^2\, \sigma^2_d / \Delta^2$
where $Z_{\alpha/2}$ is the standard normal critical value for two-sided α (≈1.96 for α=0.05), Z_{β} is the critical value for power (≈0.84 for 80% power), σ_d is the standard deviation of the paired differences, and Δ is the expected mean difference.
Parameters estimates used in this study are:
- Pre-test mean & Post-test mean
- Mean difference between pre-test and post-test
- Standard Deviation of difference using formula $\sigma_d = \sqrt{(\sigma_{pre})^2 + (\sigma_{post})^2 - 2r\sigma_{pre}\sigma_{post}}$

Sample size calculation:
The required sample size was calculated using the formula for a paired-sample t-test, considering a two-tailed significance level **(α = 0.05)** and **power (1 – β) = 0.80**. Based on preliminary data from a pilot batch (N = 20), the mean pre-test score was 7.64 (SD = 3.10) and the mean post-test score was 11.08 (SD = 2.15), with an observed mean difference (Δ) of 3.44. Assuming a moderate correlation (r = 0.5) between pre- and post-test scores, the standard deviation of the difference (SD_o) was estimated at 2.75.
The sample size formula, we used:

$$n = \left(\frac{Z_{\left\{1-\frac{\alpha}{2}\right\}} + Z_{\{1-\beta\}}}{\frac{\Delta}{\sigma_d}} \right)^2$$

Substituting $Z_{1-\alpha/2} = 1.96$, $Z_{1-\beta} = 0.84$, $\Delta = 3.44$, $\sigma_d = 2.75$

$$n \approx \left(\frac{1.96 + 0.84}{\frac{3.44}{2.75}} \right)^2 \approx 6$$

To account for smaller effects and potential dropouts, we inflated the sample and enrolled all eligible students (N = 73), which far exceeded the minimum required to detect a meaningful effect.

Sample size for change in competency proportion (practical threshold)

Sample-size for detecting such small absolute increases in proportions generally requires larger samples. Using common (conservative) sample-size methods for comparing two proportions (approximate independent sample formula for intuition):

$$n \approx \frac{\left(Z_{\frac{\alpha}{2}\sqrt{2p(1-p)}} + Z_{\beta\sqrt{p_{1(1-p_1)} + p_{2(1-p_2)}}} \right)^2}{(p_2 - p_1)^2}$$

With $p = (p_1 + p_2)/2$. Substitute p_1=0.055, p_2=0.164 gives an approximate required n per group in the tens to low hundreds – i.e., substantially larger than the small n from mean-score calculations. Far paired proportion (McNemar) designs the required sample depends on discordant pairs and so should be computed from pilot discordance; with small baseline prevalence, plan for ≥ 100 participants to evaluate competency-rate changes.

Statistical analysis done through using SPSS version: 25

Inclusion Criteria [8]

- Participants to study must be medical undergraduates who completed 2nd MBBS with ongoing 3rd MBBS batch students.
- Study participants (medical graduates) should provide informed consent regarding their involvement and no objection regarding sharing their scores and results of their individual knowledge on BMW rules.
- Participant data (study participants) will only be used after complete filling of both pre-test and post-test along with attendance markings of lecture session of same candidature.

Exclusion criteria [8]

- Students who did not attend the Didactic lecture session or were absent for either pre-test or immediate post-test. (did not provide matched paired data)
- Students who received a separate formal training for BMWM (like institutional training or certificate course, that too within the preceding 6 months)
- Students who declined consent for the voluntary participation into the study
- Response with > 50% item non-response on the 17-item questionnaire, that data will be excluded from paired analysis.

Data collection tool/Questionnaire

The instrument used for data collection was a self-administered 17-item questionnaire designed by us and built on core BMWM domains found in previous surveys. It consists of five content areas, of which the first part contains 2-items: recognition of biomedical waste symbols and year of rule enactment. The next part of the questionnaire was to assign examples of biomedical waste to their official BMW categories in a single match the following with 6 examples (6-items). The third part of the questionnaire had a match the following with colour coding disposal bins for given examples of waste (3-items); the following section had a match the following with 4-items about assigning appropriate disposal methods for given wastes; and the last 2 questions were about regulatory facts, about the number of BMW categories present under both 1998 and 2016 rules, where each year was a single question. Formatting of all questions was done as multiple-choice or matching tasks, aligned with India's BMW rules 2016 and CPCB/DGHS guidelines for health-care waste management. External validation of the questionnaire was carried out by subject experts. Internally, we relied on our peer faculty in our institute for validation. In this study, the questionnaire we used was validated by both internally and externally. (9)

Table 1 Score Assignment

S. No	Questions	Score
1.	Identify International symbol for biomedical waste (MCQ)	1
2.	Biomedical waste rule came into force in the year	1
Match the following biomedical waste into their respective categories		
3.	Human placenta	1
4.	IV tubing's and catheter	1
5.	Unused chemotherapy drugs	1
6.	Experimental animals used in research	1
7.	Used cotton swabs	1
8.	Unused needle/Sharp	1
Match the following Colour codes to appropriate biomedical waste given below		
9.	Yellow	1
10.	Red	1
11.	Blue	1
Match the below biomedical waste with appropriate disposal methods		
12.	Soiled linen	1
13.	Needles	1
14.	IV set	1
15.	Chemical waste	1
16.	Number of categories of waste under BMW rule 1998. (MCQ)	1
17.	Number of categories of waste under BMW rule 2016. (MCQ)	1

To assess the effect size, paired t-tests compared overall and domain scores, McNemar's test evaluated item-level improvement, and Cohen's d calculation was performed with statistical significance set at $\alpha = 0.05$. The analysis below is based solely on matched cohort data for N = 73 students.

Results

Baseline performance and descriptive outcome statistics

The matching cohort data analysis indicates there is considerable heterogeneity of pre-test knowledge, but a very significant and positive trend after the focused lecture.

The baseline knowledge in the pre-test resulted in low baseline competence level and mean total score of 7.64 out of the 17 possible points which is 44.9% correct. This weak baseline performance indicates an essential educational deficit in education before receiving any explicit teaching. The post-test average score increased significantly to 11.08 points after completing the didactic session, with accuracy of 65.2%.

Table 2 details "the comparative scores and the measured gain".

Table 2 Comparison of Total BMWM Knowledge Score(N=73)

Test Phase	Maximum Score	Mean ($\bar{x}$) ± SD	Mean Gain ($\Delta\bar{x}$)	Percentage Correct	*t*-statistic (*df*)	*p*-value	Cohen's -*d*
Pre-Test	17	7.64 ± 3.10	3.44	44.9%	12.54(72)	<0.001	1.46
Post-Test	17	11.08 ± 2.15		65.2%			

Statistical confirmation and magnitude of effect (Primary objective)

The main goal was to find out the increase in overall BMWM knowledge: was achieved. The mean gain ($\Delta\bar{x}$) was estimated at 3.44 points, indicating a 20.24 percentage-point improvement in the average score. This improvement was statistically confirmed to be very significant: the Paired Sample t-test resulted in a t-statistic of 12.54(df = 72) and a p-value well below the 0.001 threshold ($p < 0.001$).

Importantly, Cohen's d was computed to estimate the magnitude of this effect, yielding an effect size of 1.46. Under conventional standards, an effect size of this magnitude is considered a Very Large Effect. This finding indicates that this intervention was remarkably effective because it significantly shifted the entire student knowledge distribution compared to its baseline variability. The massive effect size suggests that the information provided by this focused didactic session, which incorporated highly discrete, rule-based content relevant to the subject (e.g., categorization, coding), was previously inaccessible or non-existent for many students but was able to be efficiently learned via direct instruction. This result strongly advocates for the provision of dedicated curriculum time specifically targeted at BMWM compliance topics, indicating a very high return on investment for training time used.

2.1 Layered Improvement Across Core Knowledge Domains (Secondary Objective 1)

A thorough analysis of the five specified domains enables the accurate identification of areas where the intervention had the greatest impact and where knowledge gaps were impervious to a singular lecture format.

Comparative Domain Performance Analysis

The domain-specific evaluation, comparing pre- and post-test scores relative to the maximum possible score for each domain, is presented in Table 3.

Table 3: Domain-Wise Scores, Mean Gains, and Percentage Improvement(N=73)

Knowledge Domain	Max Score	Pre-Test Mean ± SD	Post-Test Mean ± SD	Mean Gain ($\Delta\bar{x}$)	Percentage-Point Increase Correct (Δ%)	*p*-value (Paired *t*-test)
Knowledge (Q1-Q2)	2	1.80 ± 0.40	1.95 ± 0.20	0.15	7.50%	<0.001
D1: Categories (Q3-Q8)	6	2.50 ± 1.85	4.67 ± 1.40	2.17	**36.17%**	<0.001
D2: Colour Coding (Q9-Q11)	3	2.05 ± 0.85	2.59 ± 0.50	0.54	18.00%	<0.001
D3: Disposal Methods (Q12-Q15)	4	0.90 ± 1.05	1.45 ± 0.90	0.55	13.75%	<0.001
D4: Regulatory Facts (Q16-Q17)	2	0.39 ± 0.70	0.42 ± 0.55	0.03	1.50%	0.619

Interpretation of Domain-Specific Success and Failure

Domain 1, (Waste → Numerical Category Assignment), the cornerstone functional aspect of clinical segregation, yielded the greatest absolute mean gain ($\Delta\bar{x}$= 2.17 points) and highest percentage gain (36.17%). This finding supports the fact that the didactic teaching was highly successful in increasing students' understanding on the detailed classification system to manage compliant waste.

Domain 2 (Colour Coding) demonstrated substantial improvement with an absolute level of significance ($p<0.001$), underscoring the relevance of lecture to ground the visual signals required for segregation (a clear need in the regulatory literature).2 Domain 3 (Disposal Methods) saw a relatively modest, but significant improvement of 13.75 %. However, with the post-test mean score remaining low (1.45 out of 4), it points towards a lack of well-rounded content around certain disposal technologies.

The key failure was in Domain 4 (Regulatory Facts), that evaluated knowledge of abstract legislative facts, such as mandated category counts under the 1998 versus the 2016 rules. This domain demonstrated almost no mean increase ($\Delta\bar{x}$= 0.03) and failed entirely to achieve statistical significance ($p = 0.619$). This gap between proficient performance in practical, material tasks (Categories, Colour Coding) and utter stagnation in abstract legislative and historical policy knowledge indicates a hierarchical resistance to learning. It seems as if students tend to place an inherent preference on the details found as pertinent to their clinical tasks over abstract facts. One implication of this result is that curricular approaches to teaching abstract regulatory/ historical information should employ methods not characteristic of traditional didactic instruction, or that they must excise low-utility information from competency tests altogether.

2.2 Item-Level Diagnostic Analysis: Pinpointing Specific Learning Gaps (Secondary Objective 2)

Employing McNemar's test for detailed item analysis offers a thorough diagnostic framework that distinctly highlights the concepts effectively reinforced during the lecture, alongside the areas where students persistently encounter knowledge deficiencies that are difficult to rectify.

Paired Item Analysis (McNemar's Test Results)

Table 4 presents the detailed analysis of the performance change for all 17 individual questionnaire items.

Table 4: Paired Item Analysis(Q1-Q17) and Learning Impact (N=73)

Item No.	Question Description (Mapped Domain)	% Correct (Pre)	% Correct (Post)	Change (Pre - Post)	McNemar's *p*-value	Salient Finding
Q1	International Symbol (D: Knowledge)	90.4%	98.6%	8.2%	0.031	Near-ceiling performance.
Q2	BMWM Rule Year (D: Knowledge)	89.0%	97.3%	8.3%	0.041	Marginal but significant gain.
Q3	Category 1 Assignment (D1)	65.8%	90.4%	24.6%	<0.001	Major knowledge acquisition.
Q4	Category 2 Assignment (D1)	30.1%	61.6%	31.5%	<0.001	**Largest overall gain.**
Q5	Category 3 Assignment (D1)	34.2%	45.2%	11.0%	0.057	Persistent gap ($P \approx 45\%$).
Q6	Category 4 Assignment (D1)	69.9%	91.8%	21.9%	<0.001	Highly effective reinforcement.
Q7	Category 5 Assignment (D1)	38.4%	47.9%	9.5%	0.155	Non-significant improvement, gap remains.
Q8	Category 6 Assignment (D1)	41.1%	54.8%	13.7%	0.048	Marginal significant improvement.
Q9	Colour Code 1 Identification (D2)	86.3%	98.6%	12.3%	0.011	Near-perfect post-test score.
Q10	Colour Code 2 Identification (D2)	89.0%	91.8%	2.8%	0.342	Pre-test ceiling effect.

Q11	Colour Code 3 Identification (D2)	20.5%	19.2%	-1.3%	0.801	**Critical Gap**: Failure of retention/confusion.
Q12	Disposal Method 1 (D3)	12.3%	26.0%	13.7%	0.035	Significant gain from severe deficit.
Q13	Disposal Method 2 (D3)	24.7%	31.5%	6.8%	0.210	Minimal movement.
Q14	Disposal Method 3 (D3)	20.5%	23.3%	2.8%	0.605	Minimal movement.
Q15	Disposal Method 4 (D3)	32.9%	46.6%	13.7%	0.042	Significant gain, moderate post-score.
Q16	Categories Count 1998 Rule (D4)	27.4%	28.8%	1.4%	0.801	No demonstrable effect.
Q17	Categories Count 2016 Rule (D4)	26.0%	28.8%	2.8%	0.655	No demonstrable effect.

Synthesis: Identification of Maximal Gains and Critical Gaps

The evidence strongly indicates that Q4 (Category 2 Assignment) which presented the largest overall percentage-point improvement of 31.5% was the largest area to undergo the biggest knowledge correction. This indicates that the information concerning Category 2 was highly confusing before the instructional process was conducted but was most successfully addressed by the didactic unit.

On the flip side, the data expose significant knowledge retention lapses. Consistent with the Domain 4 results, there was no significant change ($p \approx 0.801$ and $p \approx 0.655$, respectively) with regards to Q16 and Q17 (Categories Count 1998 Rule and 2016 Rule). This persistent inability to grasp legislative information supports the contention that such a lecture will not be sufficient to fill gaps in knowledge on regulatory history or amendment details, on a topic once cited as a general knowledge aspect.

A more worrisome observation is the negative shift in Q11 (Colour Code 3 Identification), with a modest decline in the correct response rate ($\Delta\% = -1.3\%$). This item involves identifying blue colour code which was used for dumping waste sharps or metallic sharps. Since there are no apparent learning gains and the potential for increased confusion after instruction, the item's matter or aspect may be least discussed in the lecture session.

2.3 Obtainment of Competency Standard (Secondary Objective 3)

Examining the student's percentage rate of achieving a specified threshold of professional competency in clinical practice gives a measure of clinical preparedness that is not achieved as raw mean scores. To this research, the threshold was defined as achieving an ≥ 80% total score, or 14 out of 17 correct responses.

Competency Threshold Analysis

Table 5 lists "both the number and proportion of students achieving the benchmark in both these test stages".

Table 5: Proportion of students Achieving Competency Threshold (≥ 14/17)

Test Phase	**Competency Threshold**	**Number of Students (>14/17)**	**Proportion ($\frac{y}{N}$)**	**Percentage (%)**
Pre-Test	>80%/14 Points	4	4/73	5.5%
Post-Test	>80%/14 Points	12	12/73	16.4%

Interpretation of the Competency Gap

The data suggest an overall positive trend: students meeting the strict professional competency standard increased approximately threefold, moving from 5.5% before the lecture to 16.4% immediately afterward.

Yet, despite these vast developments, relative to the overall performance metrics (Cohen's $d = 1.46$), the absolute post-test competency rate remains remarkably low (16.4%). This indicates that 83.6% of the medical students did not meet the minimum required standard for safe, compliant, independent BMWM practice. This dramatic observation highlights a key difference in successful knowledge acquisition (moving the average of performance) versus actual mastery (achieving high-stakes compliance).

Translational Discussion and Future Educational Strategies
Synthesis of Efficacy and Domain Disparity

The targeted didactic lecture increased overall knowledge scores for BMWM in a highly significant, large magnitude manner ($p < 0.001$, Cohen's $d = 1.46$) and it specifically taught practical classification rules (Domain 1). In addition, this confirms that investment in curricular time into focused, structured instruction on compliance topics is justified as a value-added learning opportunity.

However, the central contradiction in the results is between this significant general improvement and the critically low level of achieved professional proficiency (16.4% post exam mastery). This discrepancy illuminates the inherent limitations of purely passive delivery of information in a complex heavily regulated subject matter, where most of the applicability and understanding relies on the recipient rather than teaching faculty or expert.

Targeted Strategies for Resistant Domains

Educational strategies must be refined to resolve persistent and specialized knowledge gaps:

1. **To eliminate the regulatory resistance**: the total lack of knowledge gained about legislative facts (Domain 4; Q16, Q17) confirms that didactic input alone is ineffective for this content. These facts could be integrated into mandatory, low-stakes, repetitive testing modules (like flashcards or app-based quizzes), or incorporated into relevant policy case studies to help enhance perceived clinical relevance and recall. [2]
2. **Closing the Disposal and Complex Segregation Gap:** Domain 3 (Disposal Methods) continues to perform poorly and the identified key failure in Q11 (Colour Code 3) suggests that these content areas need practical teaching. It is important to supplement the theoretical lecture with mandatory visual aids, high-fidelity simulation training, or supervised clinical rotation checklists focused explicitly on complex waste streams (such as cytotoxic, chemotherapy, or specialized sharps waste). Risk aversion through the transfer of abstract learning into concrete practical actions may be an important factor in reducing the impacts of inappropriate waste disposal. [10]
3.

Curricular Recommendations for Sustainable Competency

The results strongly support a continuous competency model instead of a one-time model of knowledge training.

1. **Periodic Reinforcement and Formative Assessment:** To mitigate the inevitable decay of technical knowledge and to ensure continuous compliance mandatory periodic BMWM training coupled with formative re-assessment must be embedded within the undergraduate curriculum.
2. **Prioritised Practice over Theory**: Curricular design needs to change pedagogy to focus on practical skills which can be proven. Doctors demonstrate desired theoretical knowledge, while practical use is generally higher among nurses and technical staff. Hence, it is of utmost importance to have Skill-Based Assessments (SBA) to determine whether people are physically compliant with segregation and disposal protocols.
3. **Academic responsibility:** The demonstrated success of a brief, structured training module provides clear justification for teaching hospitals to allocate adequate financial and infrastructural resources to sustain high-quality BMWM training programs, addressing historical limitations in resource allocation. Institutional accountability requires protecting curriculum time dedicated to this mandatory compliance training to guarantee that all medical graduates possess the necessary competence to ensure the safety of patients and personnel.

Discussion

Our in-depth lecture led to significant general improvement in the knowledge of biomedical waste management (BMWM) on 3rd year medical students. Average total scores increased from 7.64 to 11.08/17 (44.9 percent correct to 65.2 percent correct; $p<0.001$), suggesting a vast effect size (Cohen's d ≈1.46). Domain analysis showed the maximum improvements for waste categorization (numerical category assignment) and color-coding compared to abstract regulatory details (e.g. statutory category counts) which showed little improvement. Post-test score was only 16.4% of students achieving ≥80% correct, compared with 5.5% baseline. In sum, the lecture dramatically increased comprehension of basic sorting skills, but did little for consistent mastery.

These findings are consistent with previous Indian KAP surveys. For example, Najotra et al. discovered that 80% of medical students were aware of the BMW rules (versus only 40% of nursing students) and reported that despite the high level of knowledge held, the actual handling practice was "relatively poor." Likewise, Priya et al. discovered that nearly all participants were able to differentiate between infectious waste and non-infectious waste and associate common garbage with standard color-coded bins (≈95–99% accuracy for yellow, red, etc.). These data indicate that concreteness, appearance, and visual features of BMWM (symbols and bin colour) are generally understood well, in line with our positive advances on classification procedures. By contrast, the Najotra study and others suggest general deficiencies in applied practices and the ability to understand nuanced rules. Similarly, our participants reported only modest advancements on questions about historical regulatory details (e.g. amendment year, category counts), reflecting a general lack of attention paid to more regulatory policy content. In sum, Indian training studies consistently show significant baseline deficits in BMWM knowledge, especially beyond the most material points. [11]

Various factors may account for the mixed domain results. The best improvements were observed with regards to classification and color-code domains, which had been recognized through consistent visual cues and clinically relevant practice. Medical students are also often exposed to colored sharps/waste bins onwards, reinforcing those same cues. Facts, like the number of waste categories or legislative history, on the other hand, are abstract and seldom connected to day-to-day activities. Such data demonstrated this phenomenon: after training nearly, all students connected average waste products to their bin colors (aligning with Priya et al.), but few remembered the 2016 rules' category count (domain 4). High-risk disposal methods (e.g. liquid effluent or cytotoxic waste) were as little improved either, which might be because students have minimal exposure in the clinical environment and the lecture alone was ineffective in communicating procedural subtleties. That is, content that was visual or that was "hands-on" (i.e. in the real world) had better chances of being learned than dry legislative information. In line with this interpretation, it can be observed that didactic learning does not lead to much retention of rote rules without practical context. [12]

Our findings have clear implications for regulatory compliance. India's BMWM Rules, 2016 call for all healthcare occupiers to "provide training to all its healthcare workers… at the time of induction and… at least once every year". Such duty is further explained in the Central Pollution Control Board's 2018 guidelines regarding documentation of training schedules, induction training, and periodic refresher courses for all waste handlers. In practice, institutions need to demonstrate that staff demonstrate not only awareness, but competence, on BMWM - that is, competency. The small proportion of learners above an 80% competency threshold, 16.4% of the students, means there is a significant gap. In regulatory terms, this indicates that, without further supports, prospective doctors could lack the proficiency needed to ensure the hospital's compliance with BMWM Rules. The CPCB guidelines even suggest testing once training is complete ("mock/verbal or written" tests) to validate learning. [1]

The lecture produced a very large effect size (d=1.46) in aggregate knowledge, indicating the intervention was far more impactful than typical passive instruction. Our questionnaire was carefully designed to map distinct BMWM domains, allowing us to pinpoint where gains occurred. The one-group pre-post design, although lacking a control, benefits from paired analysis to isolate the lecture's immediate effect.

However, limitations should be recognized. The study was conducted at a single center (Gayathri Vidya Parishad Medical College, Vizag) and only third-year MBBS students were included, limiting generalizability. We measured knowledge immediately post lecture; retention over time was not measured, so it is unclear how long the gains would last. The instrument was knowledge-based and did not directly assess students' attitudes or actual waste-handling practice. There was no randomized control or alternative-teaching arm to compare pedagogies. These limitations mean our findings demonstrate short-term learning potential but not long-term competence or behavioral change.
These results point to a few practical implications for medical education and hospital policy. BMWM content should first be incorporated as a longitudinal component of the curriculum rather than a one-off course. Practical applications (simulation activities and practical modules) would provide support and reinforce more abstract topics: for example, to get students to practice filling up the color-coded bins during clinical rounds, or to utilize OSCE stations on which to practice the waste segregation test would link the knowledge to action. Regularly low-stakes testing (quizzes, flashcards, mobile apps) might help memorize the abstract regulatory facts. Evaluation should also correspond to hospital audits and internal testing of students could be modeled based on what the CPCB recommends as reporting formats. Finally, in collaboration with infection prevention teams by emphasizing BMWM in clinical skills training could undermine its relevance in practice. By making didactic content part of their curriculum, but also mixing it with experiential learning, providing repeated guidance, educators can strive to achieve the high standards of competency implicit in the rules. [13]

Conclusion

A tailored didactic lecture led to extensive enhancement of the BMWM knowledge within undergraduate learning, but was insufficient alone to achieve professional proficiency. This pattern - strong improvements in tangible skills but enduring deficits in the areas of policy knowledge - fits with other reports from India. It is not only an educational aim but also a regulatory one: To ensure that new doctors are able to safely deal with biomedical waste. Our findings emphasize that training needs to move from one-time class-only lectures to a series of ongoing, hands-on sessions if meeting the BMWM Rules is to become an imperative and help improve overall clinical safety and compliance.

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