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Effectiveness of a Plan–Do–Study–Act Cycle–Based Energy and Water Stewardship Intervention in Intensive Care Units: A Quality Improvement Project in a Tertiary Care Hospital, Gurugram, India

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ABSTRACT: The Intensive Care Units (ICUs) is a clinical setting with a high amount of resources flowing through the space, high traffic 24-hour nursing area, and would be assessed on energy and water environmental responsibility and quality improvement. This study aimed to explore the feasibility of the PDSA approach to increase staff knowledge and decrease resources usage and improve the work practice of staff in tertiary care hospital, Gurugram, India. The project carried out in two cycles of PDSA, 50 nurses, 15 technicians and 15 GDA/housekeeping staff were involved in the project in ICU for 45 days. The interventions used were: education, demonstration, education + reminder and a poster, check list, audit feedback, reinforcement and stewardship and accountability champions. Practices in cycle 2 were fully adhered to by nurses and technicians (100%) and there was an increase for the GDA/housekeeping (93.3\%). Based on the denominations of occupied-bed electricity, diesel and water in April, respectively, the cross-sector denominations in occupied-bed economy by electricity, diesel and water rose by 17.7%, 54.9%, 11.25% on average.

1. INTRODUCTION

The process of healthcare at the same time, is a participant in protection of health and pressure in the environment. Many of the services that a hospital might need include energy, water, transportation, material services, pharmaceutical, information technology (IT), sterilisation, HVAC, waste management and others. Because of the contribution that healthcare makes to greenhouse-gas emissions, air pollutants, nutrient pollution and scarce water use, it is not 'theirs' but it is also connected to the resources that we must provide to deliver healthcare care [1][2]. To preempt existing problems, the World Health Organisation

(WHO) have taken on all the three elements of safe water and sanitation, sustainable energy and appropriately supported healthcare personnel and resilient infrastructure as part of a climate resilient and environmentally sustainable healthcare facilities [1]. This is particularly the case in intensive care, where patients' safety and availability of resources go together.

ICUs are the hospital's costly space that are equipped with several machine based systems of life support and/or monitoring systems which operate around the clock and environmental conditions must be well monitored. Electricity, waste, equipment/building operation, gas and consumables have been found as critical areas with greater impacts on their environmental footprint in critical care through recent reviews [7][19][20]. Some methodological differences exist within the carbon footprints in critical care and similar emissions are measured on other environments The critical care carbon footprints vary a bit and similar measurements are performed on other environments. But the facts suggest that although critical care has measurable environmental effects, they can be minimized by making critical care more efficient and sustaining the quality of patient care. Energy efficiency, resource consumption, waste reduction, sustainable purchasing and employee education and institutional policy are three areas where action is possible and all have been included in the ESICM Green Paper 2024 hierarchical list for action towards greening of critical care [21].

Don't watch the costs of lights when you can: Not everyone can afford to do that! Constant power supply to ventilators, patient monitors and indicators, infusion pumps, dialysis and extracorporeal therapy, refrigeration, lighting, information, infection management and emergency management. So their aim is then to eliminate the unnecessary costs wherever possible, and to maintain vital clinical functions. While the thrust of the Mukurti Committee is towards energy efficiency, the Indian National Programme on Climate Change and Human Health [1] and the WHO policies [13][15] focus on the provision of reliable energy services and context specific interventions in the energy infrastructure. Simple staff-level solutions include turning off lights and equipment when it is not needed if safe, identifying any "phantom loads", equipment issues and reporting them and reminding people of the proper use of the environmental controls.

This yard stick must be applied by this water steward. Water supplies are available for hand hygiene, hospital physical processes (sterilisation), health services, food services, laundering and sanitation in hospitals and with patients. Hence the treatment and care need to be clinically safe and has to be done ahead of the infection occurring. Denominators, such as "bed-days" can be implemented by water and energy metrics, without losing this tool for learning in the hospital about the intensity of resource use, and comparing their performance over time [18]. Furthermore, the Indian "green healthcare" guidelines have been introduced which have made water conservation along with energy conservation and smart buildings an integral part as well.

One of the challenges of sustainability policies is being able to push them from desk to bed! The multiple operational decisions to utilize a resource may be referred to as decisions regarding operations, which may be limited by lack of knowledge or knowledge implementation: workload, training and knowledge level, training, knowledge and support level of the organization, competing priorities and lack of feedback system. However, a mixed picture was observed across the different healthcare professions regarding their environmental concerns with majority were concerned with the environmental impact whilst there was a huge lack of knowledge and implementation [8]. Other recent nurse studies demonstrate links between sustainability and environmental awareness with EE, an environment-friendly work culture, leadership and opportunity to act [23][24]. The need of the hour to train the numerous people working in ICUs in this multicentric search for “green” ICUs in India was stressed [29]. These findings suggest that education and presentation of an environmental cue is a better approach than providing just awareness; providing accountability, feedback and organization reinforcement.

The interaction of the quality improvement methodology could be applied to the problem as interventions will need to be applied in a context-specific manner, and may likely be an iterative process for promoting sustainability. By stating a problem, the team will implement a small scale change, review for changes and outcomes and either adjust the change or re-implement the PDSA cycle. Examples of the use of the PDSA to introduce iterative change in relation to the process of measurement [11] and involving stakeholders (a process of adaptation) can be found in literature. During the recent years all the other Green ICU practice experiences have been struggling with developing a "baseline", identification of the "hotspot areas", the creation of multidisciplinary teams, the definition of interventions and the institutionalization of the best practices identified [20, 21, 27].

The necessity of this work is just further enhanced given the key areas India will have to address – climate change and healthcare. For the first time in the Guidelines for Greening of Healthcare Facilities and Buildings 2023, National Centre for Disease Control has also selected buildings' energy efficiency and water management as one of few important areas to greenerate healthcare facilities [15]. The measurements, governance, resource optimisation and implementation of low carbon, climate resilient health systems at the health system level are also included.Inleads, there is also attention to measurement, governance, maximising resources and implementation — at the health system level — for WHO's operational planning framework for the health systems for low carbon and climate resilient health systems [14]. There is not much to be found of nurse-driven and energy/water consuming reduction interventions in Indian ICU units, however. The gap in practical implementation therefore, was addressed for the present project through a structured PDSA cycle, in a Tertiary care ICU setting.

2. METHODS

2.1 Study design and setting

This intervention was carried out in a single Institutions and in some selected Intensive Care Units (ICu) was a prospective quality improvement intervention undertaken in a Tertiary Care Hospital in the city of Gurugram, Haryana, India. A time period for implementing lasted 45 days – broken down into 2 consecutive PDSA cycles. Baseline assessment of project and assessment on the cycles after day 15 & day 38, and endpoint assessment, then laying out an action plan. This was an integrated approach which combined behaviour level and operation level measurements; relying on an existing multi-disciplinary support network to help with implementing measures.

2.2 Participants and sampling

A total of 80 people, including 50 nurses, 15 technicians and 15 GDA/house keeping people joined the ICUs. Accessible but perhaps easily eligible participants had to be assigned to an position that could potentially have an impact on resource utilization decisions within selected ICUs with exposure to intervention period and the evaluation period and access to informed consent (in writing). This analysis did not include those that were temporary worker or working for an extended leave, or those that had either no or <6 months of experience working in the ICU. Only institutional records and utility log were used for obtaining utility information when it was needed.

Table 1. Participant composition

Staff group	n	% of sample
Nurses	50	62.5
Technicians	15	18.75
GDA/Housekeeping	15	18.75
Total	80	100.0

2.3 Intervention

Both an iterative process and intervention were used in the two PDSA cycles.Plan: Review of the use of the intervention was done through Cycles (PDSA 1 & PDSA 2) and opportunities for change and baseline knowledge and gaps were identified. The Do phase of the project included teacher facilitation, posters, energy and water reminders placed by teachers on switches and water taps, a practical checklist to reinforce the action to be taken around energy and water, peer accountability, audit feedback and an energy and water stewardship champion. A re-assessment of the knowledge was done as well as a review of the observed practice of the region during the Study phase, and, finally, re-view of the utility indicators. During the Act phase areas of difficulty were requested & identified and specific to guide reinforcement and monitoring during second cycle.

2.4 Measures

The aim of the study was to identify what they already knew, so a structured format questionnaire was used and adapted with energy issues and water issues being covered as a part of the role of an employee in the organisation. Structural observational method of using checklists was conducted on the following activities; Energy saving, Water saving, Optimisation and Reporting/Compliance. Seven experts from the fields of hospital administration, quality improvement/patient safety and medical/nursing had an S-CVI of 1 and a CVR assessment of 100% of the data-collection tools.Had 100% of experts and three hospital administration, quality improvement/patient safety, medical/nursing experts participate in the 100% expert content validation (S-CVI) and was also conducted with three experts from the hospital administration, quality improvement/patient safety and medical/nursing (1 for content)? Karl pearson correlation coefficient method was applied to determine test re test reliability of the knowledge questionnaire whose correlation between nurse and technician was 0.95 and correlation between nurse and the GDA/housekeeping was 0.93 whilst that of practice checklist had similar values of 0.93 and 0.86 respectively with technician. Data on the impact of utilities were obtained using audio instruments; the structure of these audio instruments was used as in the hospital chart.

2.5 Data analysis

Scores on all items of the knowledge component of all data presented for dissertation were normally distributed and hence paired t tests used to analyze them. For categorical practice outcomes McNemar's test was used. Since the data on resource use was normally distributed, multiple (mean) t-tests were used, and when data was not normally distributed, Wilcoxon test was used in the data analysis and a p-value of less than 0.05 was considered as statistically significant as explained in the dissertation. Only t-test statistics and significance levels for the knowledge outcomes are included in the thesis which are paired. The tables above do not involve in the re-construction of the test statistic or the actual p-values; for the "monthly" comparison of utilities, all of the following are used.

2.6 Ethical considerations

The data was collected after taking care of permission from institutional ethices commit and permission from administration as well.Permission from the institutional ethices commit and permission from the administration were obtained and then the data were collected. The participants all gave their written informed consent and were participants voluntarily; as well, their written informed consent was secured and reporting of the participants with participant codes and turning these characteristics from the participants into anonymous participants was accomplished.

3. RESULTS

3.1 Staff knowledge

The data for staff categories showed significant positive gains across all three staff categories as compared to baseline in the last element of the first phases of intervention; however staff categories were not consistently referred to within the original report. There is a pattern that is more obvious in the continuous scores, which can be interpreted. Nurses increased from 7.50 ± 2.92 at baseline to 17.40 ± 3.23 at post-test 1 and were 15.28 ± 3.50 at post-test 2. Technicians increased from 8.20 ± 0.94 to 15.47 ± 0.91 and then to 16.80 ± 1.97. GDA/housekeeping increased from 4.40 ± 2.64 to 8.13 ± 1.76 and then to 7.07 ± 2.05. So the lower score of the post test 2 minus the "pre test" for the nurses is an attenuation score and NOT a score for the nurses when they achieved the 'baseline' gain score (post test 2 minus pre test). Data for the paired 't' tests from baseline to post test 1 and baseline to post test 2 that are statistically significant are analysed in the thesis.

The overall score of the nurses was 18.621 which was significantly more than 12.962 (non-calculating the technical score in the thesis), and the technicians were significantly better than 16.714 whereas the GDA/housekeeping had less score than 3.162 (in the thesis). The scores of the Continuous scores are given the main description of change of knowledge as they are free of the opposing categorical percentages found in the original text.

3.2 Practice adherence

In terms of increased adherence, there was an increase when using the 2 cycles. In 'NO' category, 100% (all 50 nurses) were in this category at baseline After post test 1, 47 (94%) were 'YES' and by post test 2, all 50 (100%) were 'YES'. Among technicians, 12 (80.0%) were 'NO' and 3 (20.0%) were 'YES' at baseline; 13 (86.7%) were 'YES' after cycle 1 and 15 (100%) after cycle 2. Among GDA/housekeeping staff, all 15 were initially 'NO'; 11 (73.3%) were 'YES' after cycle 1 and 14 (93.3%) after cycle 2. McNemar results were obtained for all practice comparisons which were found to be significant ($p<0.001$).

Table 2. Key knowledge and practice outcomes

Group	Knowledge pre	Knowledge post 1	Knowledge post 2	Practice YES post 2
Nurses	7.50 ± 2.92	17.40 ± 3.23	15.28 ± 3.50	100%
Technicians	8.20 ± 0.94	15.47 ± 0.91	16.80 ± 1.97	100%
GDA/Housekeeping	4.40 ± 2.64	8.13 ± 1.76	7.07 ± 2.05	93.3%

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3.3 Energy consumption

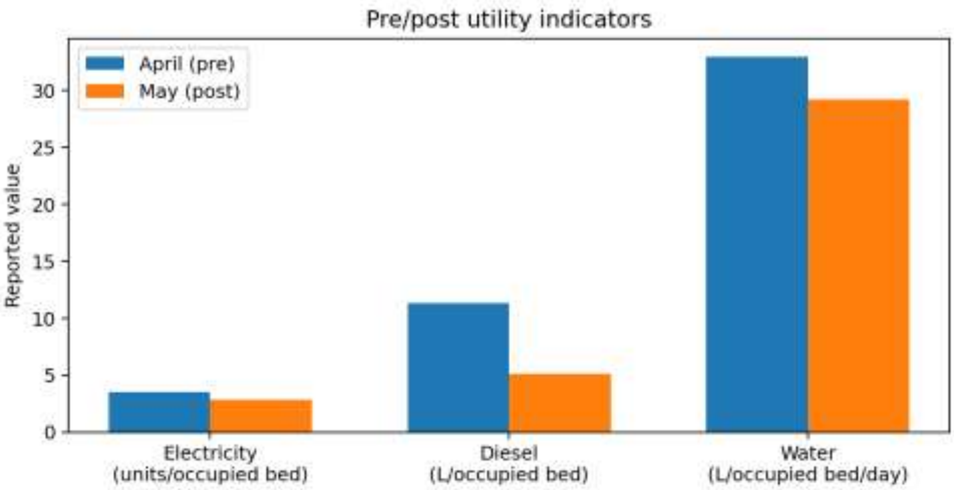
The electricity base use in April was 3.4930 units per occupied bed, as was the amount of diesel used which was 11.3 litres per occupied bed. The 17.7% (rel.) and 6.1844% (abs.) decrease in electricity consumption for May 2016 is due to a 2.8746 units decrease per occupied bed in May. The distance of diesel consumption decreased to 5,1 litres per occupied bed down from 6,2 Liuo (54,9%). Further, the Specific energy cost decreased by INR 6,8437 from last year's INR 27.2800 to INR 34.1237 per sqft. However, the dissertation provides no description of a pre/post design, which is replicated, and there is no report of a test statistic, exact p value or a Confidence interval in the Energy level.

3.4 Water consumption

This is significantly better than WCDU on May (29.2 L/occupied bed/day) which is also lower than April (32.9 L/occupied bed/day). It was 11.25% as absolute reduction when compared to having 3.7L reduction per occupied bed/day. It was quite a plunge! Specific water cost decreased from Rs 0.3802 to INR 0.3378 in per occupied bed per day – an astronomical INR 0.0424. Only one month of measurements (April) and one month (May) was reported as statistically significant and specific p value or confidence interval of water reduction were not reported, nor was any utility level test statistic. Since there could not be a valid paired inferential test, this is because it is descriptive data.

Table 3. Resource-use and cost outcomes

Indicator	Pre	Post	Absolute change	Relative change
Electricity (units/occupied bed)	3.4930	2.8746	−0.6184	−17.7%
Diesel (L/occupied bed)	11.3	5.1	−6.2	−54.9%
Water (L/occupied bed/day)	32.9	29.2	−3.7	−11.25%
Specific energy cost (INR/sq ft)	34.1237	27.2800	−6.8437	—
Specific water cost (INR/occupied bed/day)	0.3802	0.3378	−0.0424	—
Combined monthly utility cost (INR)	25,956,595	21,592,153	−4,364,442	—



3.5 Financial and carbon-related outcomes

The monthly utilities cost came down by INR 4,364,442 from INR 25,956,595 in April to INR 21,592,153 in May. From the thesis table, it has been found that the bed occupancy of the IPD is increased a bit from 25076 to 25220 (Bedoccupany), specific energy has decreased (Specific energy) and the specific water cost has also decreased (Specific water cost). This is a saving which is not expected in so far as the long-term element is concerned or in the recurrent cycle in general, but at which the difference is observed between the two months reported, as a result of the intervention. The carbon emission indicators for the thesis are also April (33.263) with May (16.120) respectively, the difference is 17.143 point. There are no sources or units associated with the carbon value on these here, nor is anything about the system boundary or even the formula used to calculate the carbon value given, it's just simply provided as an indicator of the project, and not as a carbon metric.

3.6 Overall outcome

Positive direction of change was seen in all three outcome strips, two indicator strips (amount of change from baseline in the knowledge strip, strengthening of practice adherence) were also seen as significant positive change and electricity, diesel and water indicators were reduced between April and May. Behavioural outcome – practice adherence was halved for nurses (from a high of 50% to 100%) and almost halved for technicians (from 32.5% to 93.3%) as well as the amount of diesel being used. These results indicate that the quality improvement (QI) led to month to month improvements during that period, but not necessarily that it was the PDSA intervention that caused the utility reductions.

4. DISCUSSION

Conforming to the literature and literature review, the baseline knowledge findings showed that most of the actors of the current health care have knowledge of the importance of sustainability issues, although no direct sustainability training and no sustainability resources available in the supplier to directly apply the principles of sustainability. Further, Lister et al. noted that knowledge dissemination and uptake requires the healthcare system to be a factor while concerns over environment existed among healthcare workers in SA [8]. Limited formal sustainability education, and reported sustainability-oriented bed side practices, was also reported in a study which was conducted for a Green ICU in India (at a Multicentre study).

It is important to note that for lower levels of achievement in the post-test shown by the nurses and WHO GDA (housekeeping) staff does not imply that the intervention was ineffective. Significant group improvements were observed from baseline with scores in post-test 1 still showing declines. So there would be a sub-set of rats where they remember well (fast rate) and another sub-set of rats where they don't remember things that they do remember (slow rate). Important, this also contributed to high percentage of 'adherence' from the technicians/nurses (100%) and from the GDA/housekeeping (93,3%) remained high. The result of this will be that behaviours will become habit, if it is equally 'environmental' words like 'check lists', 'peer accountability' and words of repetition and reinforcement. Educational interventions have a higher rate of adoption if they really are embedded in a capitalized system – structures – rather than a training.

The results of the practice are important to nursing quality improvement. Nurses represent a large proportion of the health care workforce and are confronted with a position in which they have to deal with patient care, the use of instruments and equipment, task execution of cleaning, coordinating patient care and engaging in interdisciplinary collaboration. When examining the sustainability indicators in hospitals [18] a part of the nurses work is shown to be directly or indirectly related to a number of sustainability indicators. The new nursing research also shows that key areas for being agents of environmentally sustainable health care are: education, nursing leadership and Green teams and organizational support. The intervention resulted in that job, through the use of stewardship champions, reminders and check in observation + peer accountability. If one doesn't acquire this, their will might not be sufficient and if they do acquire them, then the motivation of the individual may be more sustainable.

Therefore the operational aspect is more relevant in the present case of energy and the operational relevance interpretation of the results should be carried out with some caution. The drops in the electricity and diesel consumption per occupied bed were significant, with a reduction in electricity consumption per occupied bed of over 18.7% and a reduction in diesel consumption per bed of 54.9%. These changes are in line with the energy efficiency studies conducted that recommended the reduction of energy resource usage in critical care by implementing energy-efficiency programs [26] as well as the targets set by the Indian Government and WHO regarding energy efficiency and green buildings [1,13-15]. But, since there is no longer time series and concurrent control, alternative explanations of the sequence of results can be taken into account. # Changes in occupancy (e.g. patient bed changes), patient acuity, change in equipment intensity and maintenance-infrastructure change/generator operation/temperature can influence the electricity or diesel related demand.

It can also be applied to stewardship, but not to water use (as water use was decreased by 11.25% compared to hand hygiene, sterilisations, sanitisations, infection prevention and patient safety (new) - stewardship). One of the variations is operational denominator (litres of water/occupied bed/day) that is a comfortable measure of the service volume [18]. Water cost (INR 0.3802 to 0.3378) for the specific water cost occupied bed/day was seen to be decreased simultaneously. On the other hand, nothing can be concluded about the reduction from a comparison of next month's figures alone and in regard of its further course should there be a corresponding difference of occupancy and of seasonal and maintenance or operating conditions.

The > INR 4,364,442 difference in utility cost for the observed business proposition of stewardship, supports the business proposition of stewardship. The overall income for this apartment remained at INR 25,956,595 throughout April and INR 21,592,153 during May however, there was a slight increase in occupancy in April. This doesn't necessarily mean that this "savings" or "saving" is minimalistic; it is limited to the action. Staff behaviours will vary in terms of occupancy and demand and associated maintenance costs; each staff will have different scenarios. The figure and saving could have been preceded by the word 'potential' and the saving could have been stated as a condition, that it should 'be retained' in 'similar condition'.

One of the strengths of this project is staff, practice and utility data but this also provides an interesting topic of learning. Many sustainability assessments, however, consider only infrastructure or carbon footprint and many staff KAP studies would not include the measuring of behaviour change interventions; many resource measures actually are not reported. This present project made the connection in two levels. It also used two cycles – with in the 2nd cycle pre/post educational visits, which build on learning in the 1st cycle. This ensures iterative approach towards the PDSA, and also the current concept of the Green ICU practice which emphasizes on measurement and adaptation, and eventually institutionalisation [11][20] [27].

The internal validity, measurement validity and generalisability are related to the limits. First, no concurrent control study was conducted and the study was only carried out in one centre. Secondly, a comparison was made between one month at baseline and one month following their intervention which decreased the season, occupancy and time since placement of the utility. Thirdly, there is no standardisation of patient, HVAC use, infrastructure/equipment availabilities and maintenance. Fourth, the measurement evidence provided for the thesis was greater than was originally reported in the paper: while there are seven measurement experts reported to establish content validity (S-CVI = 1), there is only description of CVR for each staff group; and description of test-retest for each staff group. Fifth, the missing data detection/correction feature for the utility meters has not been well documented and the technologies used to compute meter occupancy denominators are not well documented. Sixthly, the carbon indicator hasn't been self-reproducible, due to missing units and emission factors, as well as missing boundaries and calculation equation. Last but least, the durability of the dress won't be felt after 45 days.

The analysis has been done with a short time series and plans for future work involve time series that are longer (ie, 6-12 months of observations monthly before and after implementation). This would then enable the creation of "run" charts and, if enough data existed for long enough a period then the use of statistical-process-control charts would be possible. Changes in operations can be accounted for by some specific changes (concurrent ICU or other) to help with causal inference, Interrupted time series, or regression to help with occupancy changes, acuity changes and seasonality changes. Implement measures to account for instances of calibrated meter data and verified institutional data being missing to complement utility data and denominators to support occupancy / bed days. Make it clear what is and isn't certain and specific about being able to achieve carbon reporting, while documenting activity data, emission factors, activities, system boundaries, activity units and carbon calculation equations. Elements that may be assessed for the fidelity of intervention are: attendance at training; number of reminder exposure audit incidents; incident of feedback; and, presence and adherence to paper work champion and checklist.

The Green team should be comprised of diverse individuals representing the school in aspects of health care, nursing duties and medical duties, housekeeping/monitoring duties, procurement duties/health care duties, and engineering or administration/facilities duties, all of whom participate in the school's sustainability efforts, as monitors of the situation and also contributors to its initiation of action. Other dashboards can also be created that focus on data about electricity consumption, diesel, and waste that balancing for procurement/staff practice, avoiding infections and preventing patient harm.

5. CONCLUSION

This and similar QI project activities have made it clear that it is possible to put in place a number of energy and water stewardship activities (WES) in a multi-disciplinary tertiary unit of care with a variety of simple activities such as education and demonstration, visual aides, checklist, audit feedback, reinforcement, accountability and stewardship. The nurses and technicians were 100% compliant with the practices while the GDA/housekeeping were 93.3% compliant. Combined indicators for Electricity are down by 17.7% (down by INR 220,268 on a monthly utility cost-difference basis, down by INR 5,784,440 on a denominators basis of occupied-bed) compared to April while Diesel have dropped down by 54.9% (down by INR 12,879,448 on a denominators basis of occupied-bed, down by INR 5,784,440 on a monthly utility cost-difference basis) compared to April and Water down by 11.25% (down by INR 5,784,440 on a denominators basis of occupied-bed, down by INR 5,784,440 on a monthly utility cost-difference basis) compared to April. The hypothesis test for paired t test was used to analyze the result and there was improvement in Knowledge score from the Baseline. That is partly why no test statistic is provided to compute a p value at the utility level (the absence of a utility-level confidence interval is also provided (and there isn't any test statistic provided to compute an exact p value, but only one replicate observations of the utility outcomes is reported for each pre and post period)).

Reporting note on the three revised issues. Utility outcomes are reported from the available institutional April and May records as descriptive pre/post changes. Exact utility-level inferential statistics and confidence intervals are not available in the reported source tables and have not been fabricated. The available documentation also does not establish independent meter-calibration verification, a formal missing-data rule, or independent denominator reconciliation; these are explicitly identified as measurement limitations. Figure 1 is consequently a descriptive two-period comparison rather than a run/control chart. These reporting choices preserve source fidelity while preventing unsupported statistical or methodological claims.

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