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Student and Faculty Team Measures Indoor Air Quality Attributes of Interior Building Materials, Finishes & Cleaning Products

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ABSTRACT

Researchers explored Indoor Air Quality (IAQ) associated with building materials, finishes, and bleach cleaning with their students via 1) assigned readings; 2) pre-recorded lectures delivered by IAQ experts; 3) experiments with an IAQ monitor. “Hands-on” IAQ activities were conducted in the University’s technology laboratory during 75-minute class sessions and included 1) a trial study conducted with four materials and finishes; 2) activity #1, a faculty-led experimental study with 25 students and four materials and finishes; 3) activity #2, a faculty-led experimental study conducted with 25 students and 16 building materials and finishes. Awair Element IAQ monitor was utilized to measure attributes: temperature, humidity, carbon dioxide (CO2), Volatile Organic Compounds (VOCs), fine particulate matter 2.5 Mm (PM2.5), and overall IAQ that can potentially impact health, comfort, and productivity of building occupants. Faculty researchers refined their methodology; photo-documented IAQ tests via smartphone photography and videography; developed, tested, and revised spreadsheets to organize observations; determined overall logistics. After Activity #1, an IRB-approved pre-test survey was administered to capture the students’ awareness, experiences, and perceptions regarding the IAQ exercise. After Activity #2, an IRB-approved post-test survey was administered. Findings varied across materials. This unique study utilized empirical tests to educate college students regarding IAQ.

Keywords: Indoor Air Quality, Building Material, VOC

1. Introduction

Indoor air quality (IAQ) is a very important issue to consider when designing any building. The plethora of available building materials can pose different risks to building occupants. A building's IAQ can be compromised by microbial contaminants, chemicals, allergens, or other factors that can negatively affect the health of individuals who use a building [1]. IAQ gained attention in the building industry due to its impact on occupants' health, well-being, and satisfaction [2].

Further, the pandemic has increased the frequency of cleaning interior surfaces to stop the spread of CoViD-19, but some cleaning methods and agents may cause health issues [3]. As a result of CoViD-19, bleach cleaning especially has become popular [4]. Researchers studied IAQ in various building types using monitoring and post-occupancy evaluation methods. Previous studies have investigated IAQ in University settings [5]. Current design textbooks emphasized the importance of IAQ [6]. Volatile Organic Compounds (VOCs) may negatively impact human health by causing various symptoms including those related to the optical and respiratory systems [7].

Few studies were found from the interior design sector related to IAQ. However, one research team conducted a post-occupancy evaluation survey to study the impact of IAQ on employees' perception of their health and well-being in their work environment [8]. Another research study investigated the perceptions of interior designers regarding the effects of carpets on IAQ [9].

IAQ is often introduced in interior design curricula and is included in the Council for Interior Design Accreditation (CIDA) professional standards requiring students in the United States of America to understand "the principles of IAQ" [10].

Although different studies have explored a myriad of factors related to IAQ no studies aimed at educational purposes were found exploring carbon dioxide (CO2), total volatile organic compounds (TVOC), particulate matter 2.5 (PM2.5), and overall IAQ levels of commonly used building materials. No studies were found that utilized empirical tests to educate college students about IAQ monitoring. No published studies were found in which undergraduate design students participated in empirical IAQ research.

Further, no evidence was found of published empirical studies from the interior design sector involving student monitoring of IAQ utilizing various materials and finishes or bleach cleaning. According to Kolb's Experiential Learning Theory (2014), people learn through the

transformation of their experiences. The current faculty researchers propose that experience-based IAQ education should be utilized and assessed in interior design courses.

2. Methodology

2.1 Trial Study, Activity #1, and Activity #2

Over the course of the 16-week (refer to timeline in Table 1) Materials and Finishes for Interior Design course in Fall, 2021, a student and faculty research team explored Indoor Air Quality (IAQ) associated with building materials, finishes, and bleach cleaning with their 3rd-year students via 1) assigned readings in the course textbook, 2) pre-recorded lectures delivered by IAQ experts, and 3) experiential participation in IAQ monitor activities conducted in-class with a total of 16 interior materials and finishes and cleaning products (refer to Figure 1-2). These "hands-on" IAQ activities were conducted in the University's technology laboratory during 75-minute class sessions. Activities included 1) a trial study conducted on August 16th, 2021 by the faculty members with four materials and finishes, 2) activity #1, a faculty-led experimental study conducted on August 30th, 2021 with 25 students and three faculty utilizing four materials and finishes, and 3) activity #2, a faculty-led experimental study conducted on September 27th, 2021 with 25 students and three faculty utilizing 16 building materials and finishes.

An Awair Element IAQ monitor was utilized with a mobile phone app (Awair Home) on an Android Phone (Model: Google Pixel 5) to measure five attributes in the experimental studies: temperature, humidity, carbon dioxide (CO2), Volatile Organic Compounds (VOCs), fine particulate matter 2.5 μm (PM2.5), and overall IAQ that can potentially impact health, comfort, and productivity of building occupants. Four student sub-teams of three or four students were assigned to four different material samples, finishes, or cleaning products. During the studies, the methodology and logistics were refined; tests were photo-documented; and a spreadsheet to organize observations was developed, tested, and revised. The teams recorded the IAQ monitor readings on a spreadsheet the researchers had developed. Researchers utilized a hairdryer to warm some wood samples. They applied the paints/coatings with disposable paintbrushes onto a cardboard substrate. Eight different materials were used: 1) Oriented strand board (sawn), 2) Oriented strand board (sanded 1.5m away from IAQ monitor), 3) Oriented strand board (sanded 0.15m away), 4) Oriented strand board (previously sanded 1.5m away and warmed with a hair dryer), 5) Penetrating wood stain, 6) Indoor paint, 7) Oil-based odorless stain blocker, and 8) Interior/exterior spray paint.

The team took a baseline reading of the classroom IAQ and subsequently monitored materials and finishes for one minute each. After monitoring each material, finish, or cleaning product, portable fans were energized, to aid in resetting IAQ values between samples to the baseline. Teams recorded time and noted monitor readings. Descriptive statistics, including averages, minimums, maximums, and standard deviations, were reported.

2.2 Pre and Post-test Survey

The pre- and post-test surveys targeted 26 third-year interior design students (18 – 29 years old) enrolled in the Materials and Finishes for Interior Design course. The research team designed a questionnaire to assess students' learning experience related to IAQ of building materials and finishes. The questionnaire included items that assess students' knowledge of some terms such as VOCs and empirical studies. It also included items to assess students' satisfaction with their learning experience.

The surveys were designed and administered based on Dillman's method for online surveys to maximize the response rate [11]. The surveys were designed to be completed in about 10-15 minutes and emphasized the confidentiality of responses. The course instructor provided the research team with a list of students' email addresses. The research team created a tailored email that addressed this specific group of students and explained how the participants will benefit by receiving five extra credit points for the Materials and Finishes for Interior Design Course upon completing the survey.

The research team submitted an Institutional Review Board (IRB) application which was processed as "exempt". The research team surveyed students online and after the students had completed the IAQ activity in class they sent out the first email to potential respondents with an anonymous Qualtrics survey link. The research team also shared the QR code as an alternative way for respondents to access the survey. Then, a survey reminder was sent out two days later, and a second reminder was sent out four days after the completion of activity #1 and activity#2.

The Mann-Whitney U test was utilized to evaluate the difference between the medians of the pre-test and post-test variables measured on the same subject sample. The sample used in this analysis consisted of 21 interior design students for the pre-test survey and 22 interior design students for the post-test survey. Even though the survey was anonymous, the respondents were asked to insert the four first letters of their mother's maiden name. The research team intended to use this data to match responses from the pre-and post-test surveys. Due to the relatively small sample size, the variables were found to present violations of the

normality assumption of the paired sample t-test. Therefore, the Mann-Whitney U test was selected for this analysis as an alternative to the paired sample t-test. The null (H0) and alternative hypothesis (H1) are listed below:

H0: The median of the differences between the variable responses was equal to zero in the total population.

H1: The median of the differences between the variable responses was not equal to zero in the total population.

Table 1 Timeline for Study in the 16-week Class

		Week														
	Description	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	IAQ readings assigned to students	■															
2	Trial Study (faculty only)	■															
3	Activity #1 (demonstration for students)			■													
4	Pre-test survey			■	■												
5	Activity #2 (in-class activity for students)							■									
6	Course quiz							■									
7	Post-test survey							■	■								
8	Final Exam																■

Figure 1 Faculty Conducting the Trial Study.

Figure 2 Students and Faculty Team Conducting the Study.

3. Research & Discussion

3.1 Trial Study

The researchers' field notes revealed overall IAQ attributes as follows: temperature: 73.4°F (23.0° C) and relative humidity: 65%. Further, researchers recorded individual measurements of IAQ attributes for the eight materials. The IAQ monitor tests showed variability across samples. Refer to Table 2 for the average scores for each material for C02, VOC, and PM2.5. The oriented strand board (previously sanded 1.5m away and warmed with a hair dryer) was found to have the highest C02 value recorded at 599ppm. However, the exterior/interior spray paint was found to have the highest values for both the total VOCs (13,242ppb) and PM2.5 (369.17ppm). Values that are greater than 8,332ppb (parts per billion) for TVOC values and 75µg/m3 for PM2.5 values could result in serious health concerns including cognitive impairment, overworked liver and kidneys, respiratory illness, and/or cancer [12]. Therefore, the recorded values for the exterior/interior spray paint from the trial study exceeded the recommended levels. All the other materials showed a variety of measurements, but they did not exceed the recommended values.

Table 2 Trial Study with Measurements for Eight Different Materials

#	Material	CO_2 (ppm)	Total VOC (ppb)	PM2.5 (µg/m^3)
1	Oriented strand board, sawn	500.63	22.13	24.00
2	Oriented strand board, sanded 5ft away	513.00	23.50	8.25
3	Oriented strand board, sanded 6in away	516.33	23.00	61.50
4	Oriented strand board, sanded 5ft away, warmed with a hair dryer	599.00	21.00	17.17
5	Penetrating wood stain	512.00	671.16	4.20
6	Indoor paint	540.50	125.33	4.20
7	Oil-based odorless stain blocker primer	501.00	199.82	1.73
8	Interior/Exterior spray paint	486.17	13342.00	369.17

3.2 Activity 1

The temperature and relative humidity values recorded for this activity were 74°F (22.2°C) and 48% respectively. The highest average CO2 value reported was for the spray paint and the lowest value was for the bleach wipes. The spray paint also had the highest values for total VOC and PM2.5, both of which exceeded the recommended levels. This also resulted in the spray paint having the worst overall IAQ value. The Merino wool natural carpet and the

bleach wipes had the lowest total VOC and PM2.5 values respectively. These two materials also had the highest overall IAQ value as a result. The natural edge plywood had a lower overall IAQ value when compared to the carpet and bleach wipes. The lower overall IAQ value was a result of the PM2.5 value of 359.80µg/m3 exceeding the recommended level. Refer to Table 3 for the average scores for each material for CO2, VOC, PM2.5, and overall IAQ values.

Table 3 In-class Demonstration for Students for Four Different Materials

#	Material	CO_2 (ppm)	Total VOC (ppb)	PM2.5 ($\mu g/m^3$)	Overall IAQ
1	Bleach wipe	795.50	22.33	1.17	90.17
2	Merino wool natural carpet	828.63	20.88	3.25	90.00
3	Interior/Exterior spray paint	861.33	20914.00	871.70	58.17
4	Natural edge grain plywood	856.30	26.10	359.80	77.10

3.3 Activity 2

For this activity, temperature and relative humidity values were 72°F (23.3° C) and 55% respectively. Average CO2 values exhibited minimal variance amongst the 16 variables. The lowest recorded value was for the oriented strand board at 803.80ppm and the highest value was for interior paint at 976.50ppm. The average TVOC values did show significant variability across the 16 variables with values recorded as ~20.00ppb for plywood, carpet, and wool materials, 52.67ppb for interior paint, 82.33ppb for bleach wipes, 250.67ppb for oil-based stain-blocker, 319.67ppb for a wood finish, 341.50ppb for latex paint, 8,223.17ppb for enamel neutral base and 31,738.67ppb for spray paint. PM2.5 values, on the other hand, were higher for different plywood materials, ranging from 168.67µg/m3 to 778.67µg/m3. Stain blocker, enamel neutral base, nylon stain, interior paint, paint thinner, wood stain, and latex paint all had PM2.5 values under 10µg/m3. Bleach wipes and particle board had values between 15 and 25µg/m3. Oriented strand board had a value of 254.20µg/m3 and spray paint resulted in the highest PM2.5 value at 853µg/m3. Lastly, spray paint was the only material with an IAQ total value lower than 70 (56.33) which is within the range of posing significant risks to individuals. Refer to Table 4 for the average scores for each material for CO2, VOC, PM2.5, and overall IAQ values.

Table 4 In-class Activity with Students for Sixteen Different Materials

#	Material	CO_2 (ppm)	Total VOC (ppb)	PM2.5 ($\mu g/m^3$)	Overall IAQ
1	Oriented strand board	803.80	22.80	254.20	79.00
2	Interior Latex paint	846.33	341.50	3.00	90.50
3	Bleach wipes	849.00	82.83	16.67	90.83
4	Natural edge grain plywood	850.50	20.17	778.67	74.00
5	Paint thinner	886.83	22.33	3.33	94.00
6	Merino wool natural carpet	890.33	20.50	8.33	93.33
7	Particle board	881.50	20.17	23.33	90.00
8	Flat-grain bamboo plywood	886.67	20.00	74.33	80.83
9	Stain wood finish	912.00	319.67	6.00	91.50
10	Interior paint	976.50	52.67	3.67	92.17
11	Nylon carpet	958.17	20.00	7.83	92.50
12	Amber edge grain plywood	940.67	20.00	169.67	77.50
13	Flat grain plywood	936.17	20.00	168.67	76.17
14	Oil-based odorless stain blocker primer	927.83	250.67	6.50	91.67
15	Interior/Exterior neutral base paint	936.83	8223.17	2.17	79.00
16	Spray paint	927.00	31738.67	853.00	56.33

The results showed that the CO2 values were found to have the least variability among the 16 materials and had the least impact on the overall IAQ value, while TVOC and PM2.5 both had a remarkable impact on the overall IAQ value. For instance, when considering the oriented strand board and the interior-exterior neutral base paint, notice they both had the same overall IAQ value of 79, but different TVOC and PM 2.5 values. While the oriented strand board had TVOC and PM2.5 values of 22.80ppb and 254.20 µg/m3 respectively, the interior/exterior neutral base paint showed TVOC and PM2.5 values of 8223.17ppb and 2.17 µg/m3 respectively. This suggests that having a higher TVOC or PM2.5 value can result in a lower overall IAQ value. If both the TVOC and PM2.5 values are low, such as with the spray paint, then the result is a remarkably lower overall IAQ value.

3.4 Pre-test Survey

A total number of 21 responses were collected by a survey based on Bloom's Taxonomy [13] which represented an 88% response rate. Some demographic characteristics of participants were collected such as age, gender, race, and average academic grades. Results showed that most of the students (n=17, 81%) were in the age range of 18-23 years old and some (n=4, 19%) were between the ages of 24-29 years old. Also, most (n=19, 90.5%) of the students were females. Most of the students (n=16, 76.2%) were White American, while few

(n=3, 14.3%) were American Indian, and one (n=1, 4.8%) was African American. Some students (n=13, 61.9%) indicated that their average grades range between A+ and A, while others (n=8, 38.1%) indicated that their average grades range between A- and B+.

Results showed all (n=21, 100%) students were aware that ensuring good IAQ is important to interior designers. Almost all (n=20, 95.2%) strongly agreed that understanding VOCs was important to interior designers. The responses regarding the IAQ monitoring experience varied. More than half of the respondents (n=12, 57.1%) indicated that they did not have experience using IAQ monitors and third of the respondents (n=7, 33.4%) indicated that they did have experience using IAQ monitors, and a few (n=2, 9.5%) indicated that they were neutral when it came to previous IAQ monitor experience. Most respondents (n=20, 95.2%) thought it was important to learn about IAQ content and most of them (n=19, 90.4%) were satisfied with IAQ incorporation into the course. None of the students (0%) indicated IAQ was unimportant, and none (0%) were dissatisfied with their IAQ learning experience.

3.5 Post-test Survey

A total number of 22 responses was collected representing a response rate of about 85 percent. Demographics data showed that most of the students (n=16, 72.7%) were in the age range of 18-23 years old and a few (n=2, 9.1%) were between the ages of 24-29 years old. Also, most (n=17, 77.3%) of the students are females. Most of the student respondents (n=15, 68.2%) were White American, while few (n=2, 9.1%) were African American, and one (n=1, 4.5%) was American Indian. Some students (n=10, 45.5%) indicated that their average grades range between A+ and A, while others (n=8, 36.4%) indicated that their average grades ranged between A- and B+. In addition, some students (n=4, 18.2%) “preferred not to answer” the demographic questions.

Most of the responses (n=21, 95.5%) indicated that IAQ was important to interior designers. All responses (n=22, 100%) strongly agreed that understanding Volatile Organic Compounds (VOCs) of interior finishes and materials should be important to interior designers. Many students (n=20, 90.9%) believed that they have experience with IAQ monitoring. Also, all students (n=22, 100%) thought that they had become familiar with the term “empirical” regarding measurements in a scientific study. Most responses (n=19, 86.4%) indicated that it was extremely important to learn about IAQ content in the course about materials and finishes for interior design, while a few responses (n=3, 13.6%) indicated that it was slightly important. Also, many students (n=16, 72.7%) indicated that they were extremely satisfied with the IAQ content

provided in the course about materials and finishes for interior design, while (n=6, 27.3%) were slightly satisfied.

3.6 Pre-test and Post-test Survey

The p-value of the Mann-Whitney U test was found to be less than 0.05 for two variables. The first variable was the students' experience with IAQ monitoring (Z=-5.026, p<.000), and the second was students' familiarity with empirical research (Z=-5.618, p<.000), as shown in Table 5. Therefore, the null hypotheses were rejected and the median of the differences between the responses of these two variables was found to be significantly different from zero. In other words, the students provided higher scores for their experience with IAQ monitoring and their familiarity with empirical research after participating in the second IAQ activity, as shown in Table 5 below.

Table 5 Comparing Pre- and Post-test Survey Results

	Item	Pre-test Avg.	Post-test Avg.	Mann-Whitney U test Results
1	IAQ Knowledge Importance	4.92	4.67	-0.977
2	VOC Knowledge Importance	4.83	5.00	-1.024
3	VOC Understanding Importance	5.00	5.00	-1.024
4	Experience with IAQ Monitoring	2.33	3.67	-5.026***
5	Familiarity with Empirical Research	2.50	4.17	-5.618***
6	IAQ Content Importance	4.67	4.92	-0.121
7	IAQ Content Satisfaction	4.50	4.67	-0.279

***$p < .000$.

The first three items of the student questionnaire assessed the students' perception of the importance of IAQ knowledge for building materials and finishes. The results obtained from the pre-and post-test surveys showed that almost all students agreed that ensuring good IAQ and understanding VOCs of interior finishes and materials should be important to interior designers. The second two items of the questionnaire assessed students' experience with IAQ monitors and their familiarity with empirical research. The descriptive statistics of the pre-test survey revealed a variation in students' responses as shown in the charts below. The results revealed that more than half of the students (n=12, 57.1%) had no prior experience with IAQ monitoring and empirical research. After the second activity took place, the students' questionnaire responses diverged. The second set of responses showed that almost all of them believed that they had gained experience with IAQ monitoring and empirical research as shown

in Figure 3 and Figure 4. The significant results of the Mann-Whitney U test supported the descriptive results for those two variables as shown in Table 1.

Figure 3 Comparing Students' Experience Using IAQ Monitor.

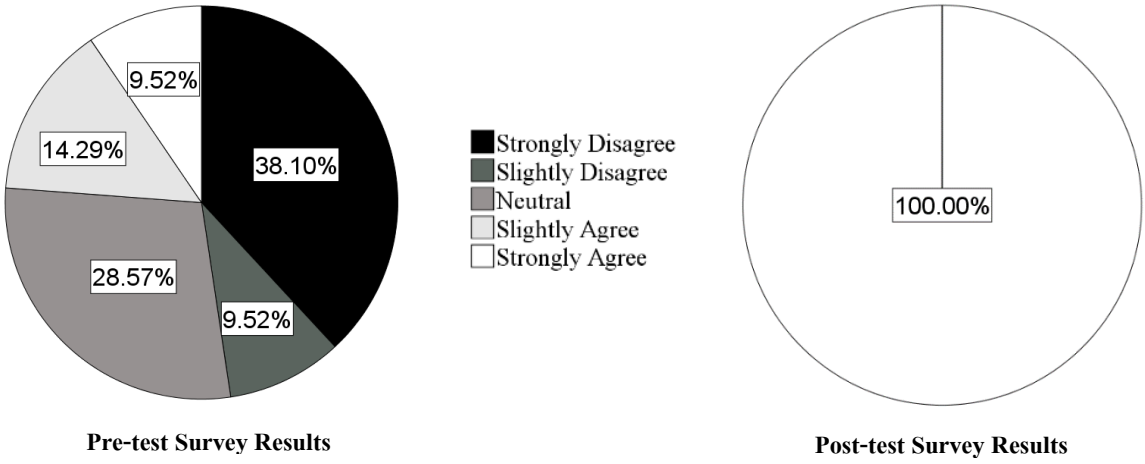

Figure 4 Comparing Students' Familiarity with Empirical Research.

The final two survey questions assessed students' perceptions of the importance of the IAQ content provided in the Materials and Finishes for Interior Design course as well as their satisfaction with the IAQ content provided in this course. Even though the Mann-Whitney U test did not show significant results for those two variables, the descriptive statistics revealed compelling information. For example, in the pre-test survey, a few students indicated that they were neutral when it came to the importance (n=1, 4.8%) and satisfaction (n=2, 9.5%) with IAQ content. The students' responses to the post-test surveys revealed that the students'

perceptions were divided between slightly satisfied and strongly satisfied, as shown in Figure 5 and Figure 6.

Figure 5 Comparing Students' Perception of the Importance of IAQ Knowledge.

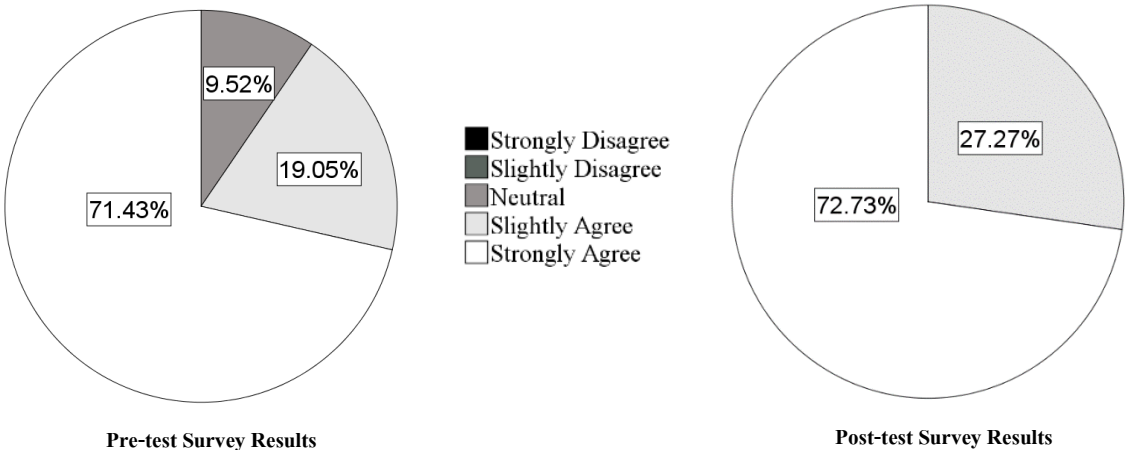

Figure 6 Comparing Students' Satisfaction with Learning about IAQ.

Both descriptive and empirical statistics showed that the IAQ activity conducted in class improved the students' knowledge about IAQ monitoring and empirical studies. Also, descriptive statistics indicated that students' perception of the importance of and their satisfaction with IAQ content improved after the second IAQ activity was conducted in class. Those results indicated that interior design students showed curiosity, interest, and willingness to learn more about the technical aspects of building materials and finishes. It was also clear that the hands-on activity and the incorporation of the empirical study which utilized the IAQ

monitor as part of the activity had increased students' engagement with interest in and motivation to learn the technical information provided.

3.7 Limitations

A limitation identified by the research team was that the standard furniture layout in the classroom hindered students' interaction during the activity. Due to CoViD-19 protocols, furniture re-arrangement was not allowed. However, in future activities, it would be best to adjust the room layouts to enhance logistics and students' engagement. The student surveys were conducted with a relatively small sample from one course and are therefore not generalizable.

3.8 Recommendations for future

The faculty educators propose that experience-based IAQ education should be utilized and assessed in interior design courses. In future research, more materials could be empirically monitored for longer periods. Also, future studies of correlations are recommended, which could go beyond students' perceptions of their knowledge of IAQ content as revealed in surveys. Future studies involving IAQ in multiple courses, and in multiple disciplines at multiple universities are recommended.

3.9 Implications

Creating interior design students' awareness and understanding of empirical IAQ testing for different building materials could potentially influence the materials they decide to specify or avoid in their future professional careers, potentially making buildings healthier for their occupants.

4. Conclusion

Indoor Air Quality is an important aspect of the Indoor Environmental Quality criteria of buildings. It affects the occupants' health and well-being and has been studied immensely in multiple fields. However, very little to no research addressed IAQ monitoring as an educational activity. This study aims to establish a methodology for introducing IAQ empirical tests as an educational learning experience. The methodology included selecting an IAQ monitor that is user-friendly and relatively simple to use. It also included selecting a variety of interior building materials, finishes, and cleaning products. The materials were selected to demonstrate different properties that can help students' learning.

The research team experimented with the selected materials in a trial study. Then, a brief activity was conducted including students who tested four materials only to familiarize them with the empirical study. A few weeks later an extensive activity took place in which students monitored IAQ for 16 materials. The research team developed an excel sheet for students to record the IAQ monitoring results. Students were handed safety data sheets (SDSs) for each material to complement the experiential activity with theoretical knowledge.

Findings from the trial study, activity #1, and activity #2 suggest that CO2, TVOC, PM2.5, and overall IAQ levels should all be considered when designing buildings as materials can contribute differently to buildings' IAQ levels. Using empirical test protocols in the classroom may help students to connect more viscerally to IAQ concepts when using real-world building materials and seeing outcomes first-hand. Students may be more likely to share material selection best practices or IAQ assessments with other practitioners in the future.

The research team conducted pre- and post-test surveys to study the students' perceptions of and experience with IAQ monitoring before and after the in-class monitoring activities. Results revealed that most students were aware of the importance of IAQ knowledge. Results also indicated that the IAQ activity had advanced the students' experience and made them more familiar with IAQ empirical research. Finally, students appreciated the incorporation of the IAQ activity as part of their learning process.

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