The Fluor-essence of Design: Classroom Lighting and Acoustics

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Executive Summary

In the fall of 2015, students in the Sociology/Anthropology 371 course conducted research on formal and informal learning spaces at St. Olaf College; our section focused on formal spaces. We conducted an anonymous online survey through St. Olaf Form Creator with a sample size of 750 students. Our response rate was 38% (285 respondents).

Our team's research focused on three variables associated with acoustics and lighting in the classroom: student satisfaction, student distraction, and student preference. We investigated two research questions:

1. How satisfied are students with the acoustics in their classrooms and what aspects of acoustics do students find distracting?
2. What type of lighting do students prefer for specific activities in formal learning spaces (e.g. for lectures, group discussions, exams, presentations, movies, etc.)?

The most important results are:

- While most students are satisfied with acoustics, one in five students is distracted by some sort of noise during class.
- Classroom speaker and microphone technologies should be as user-friendly as possible to minimize instructor error.
- Classroom design should incorporate acoustic isolation strategies to minimize both exterior and interior noise.
- Students indicated that their acoustic satisfaction hinges on the consistent elimination of distractions through sound insulation as well as technological consistency.
- Students generally prefer natural lighting, but a combination of both natural and artificial is ideal.
- Classroom design should include controls for all lighting elements.
- Installing light fixtures on walls rather than hanging from ceilings in order to make bulbs more accessible can help eliminate two common problems: flickering lights and dead bugs stuck inside light fixtures.

Based on our research, we offer three recommendations:

1. Incorporate acoustic insulation strategies to minimize both exterior and interior noise.
2. Design classrooms with both windows and electrical lighting.
    - Incorporate controls to make a combination of natural and artificial light easy to control and flexible to change between.
3. Design classroom lighting to be able to accommodate a variety of classroom activities by incorporating lighting control that can turn off specific lights rather than all lights or no lights.

BACKGROUND AND LITERATURE

Learning spaces in higher education have been changing rapidly. Universities and colleges have been paying more attention to space design as students increasingly perceive traditional classrooms to be rigid and obsolete (McArthur 2015). Though some learning takes place in informal spaces such as libraries, gathering spaces, and corridors (McDaniel 2014; Painter et al. 2012), the vast majority of student-instructor interaction still occurs in formal learning spaces used for regularly scheduled classes. These include but are not limited to lecture halls, traditional classrooms, technology-infused classrooms, laboratories, and active learning classrooms (Painter et al. 2012).

Many colleges and universities across the world have adopted the traditional method of teaching with a podium in the front of the classroom and all of the seats facing in that direction. This arrangement has been the main way in which professors at the highest level of education have taught. As college impact models and cohort studies have shown, instructor and student socialization progresses generationally (Ihrig 2014; Weidman 2006). In his article describing the history and evolution of active learning spaces, Beichner (2014) suggests that likewise, classrooms should evolve generationally. He gives three reasons as to why classrooms should change: the world is a different place, information is readily accessible, and the students are different. He goes on to explain that although the traditional lecture-style learning has been successful, millennials are much more tech savvy, and we should use more modern approaches in the ways students learn. Thusly, St. Olaf's recent innovations in formal learning space design in Regent's Hall of Natural Sciences (including integrated technology in formal learning spaces as well as tiered classrooms designed to foster classroom interaction) represent significant progress toward meeting student needs (Van Wylen et al. 2011).

Some examples of modern approaches include technology-infused classrooms and active learning classrooms (ALCs). Technology-infused classrooms closely resemble traditional classrooms but include technologies such as overhead digital projectors, podium computers, and video viewing capabilities (Painter et al. 2012). ALCs may differ from other spaces by including "easily moveable furniture, readily accessible outlets, ports, computers, mobile whiteboards, projectors, video, Internet, and/or other learning accessories," (Painter et al. 2012). ALCs aim to eliminate student-instructor hierarchies, accommodate diverse pedagogies, and engage students interactively.

St. Olaf College's 2016 Framework Plan will continue to take advantage of recent progress in the field of learning space design by focusing on many different aspects both formal and informal learning spaces. Our team's research focused on lighting and acoustics in formal learning spaces.

Lighting and its Effects on Learning

In 1965, a team of researchers asked over 1,000 15-year-olds to draw their ideal classroom. Students who were taught in classrooms with windows drew roughly the same type of classroom they were already in. However, students who normally learned in a windowless classroom drew spaces with even more windows than those students who actually had them. Studies like this sparked the conversation about lighting and its role in the classroom (Cobham 2013).

Different types of lighting can have vastly different effects on learning, and it has been shown that when teachers are able to choose the type of lighting in the classroom, students' concentration increases (Cobham 2013; Sleegers 2012). In one study, for example, teachers were given the option to choose between energy setting (cold, white light intended to activate pupils), focus setting (a bright, white light aiding concentration), calm setting (white, warm light bringing a “relaxing ambience”), and a standard setting (standard lighting found inside used for regular classroom activities). Student performance and concentration increased significantly when the teacher had control over the lighting and could change it based on the particular classroom activity (Sleegers 2012). Research by Mott et al. (2012) has also found that instructor control over lighting color temperature (measured in Kelvin), ranging from ‘cool’ (blue and white) to ‘warm’ (red and yellow) along the radiation spectrum of light” (2012:3), as well as “lighting illumination intensity” (2012:3), lead to increased student focus. On the other hand, lights flickering and glare tend to decrease overall performance. Research by Knez (1995) measured the effects of color temperature and illumination levels on overall task performance and mood in males and females. Males performed better in cool, white lighting while females performed better in warm, white light. However, while lighting temperature and illumination did not increase positive feelings in males or females, cool light had a more negative effect on females’ moods thus decreasing their overall performance in cool lighting.

Overall, research on lighting in the classroom has found that flexibility is essential to performance, concentration and learning (Davis 2012). While it is important that instructors have the option between natural and artificial light, it is even more important that they can seamlessly adjust both types of light for the desired learning effect in order to enhance students’ education.

Acoustics and its Effects on Learning

Acoustics is an additional element to take into account in formal learning spaces. Acoustic issues range from inability to hear classmates in small group discussion to noises from the building itself (pipes, fan, buzzing light, etc.). Many of the articles that speak to acoustic qualities and distractions mention that main causes of acoustic distraction of teachers and students included the position of the building in relation to recreational spaces, noise generated from neighboring classrooms, and noises from the room itself such as students moving around or squeaky floors and school equipment. Findings suggest that a main error in the design of the schools is the position of classrooms near regions where levels of traffic noise are high (Zannin et al. 2009; Zannin et al. 2012). Zannin (2009) measured the external and internal ambient noise levels in school buildings in Parana, Brazil to test the acoustic quality of the classrooms. The main error for placement of the school building was that schools were too close to recreational spaces, which caused higher levels of acoustic distraction for students inside classrooms. Further, slotted glass vents in the walls separating the classrooms from the halls allowed noise from the other classrooms and from the hall to penetrate into the classroom, thus increasing ambient noise (2009). In contrast, another study by Zannin et al. (2012) observed schools that were under investigation to assess whether the schools met building standards. Six of the schools under investigation were placed in regions where the levels of traffic noise were not bothersome inside the classrooms, meaning outside noise was not a distraction. The reason these six schools had low noise levels was largely due to the sound insulation of both facades and dividing walls. These types of dividers allowed for a separation between classrooms and between hallways and classrooms, allowing little to no noise penetration into classrooms. One suggestion for the improvement of acoustic ambience was to place perforated plywood in the ceiling to reduce in reverberation time and increase the acoustic comfort of the classrooms (Zannin 2007). Another suggestion to improve the facade insulation was to substitute ordinary windows for double-paned windows.

Research on comfort levels of acoustic in the classroom have shown that teachers and students consider noise generated by voices of the teacher in neighboring classrooms is one of the main sources of annoyance for students and teachers (Zannin 2007). A questionnaire was sent to teachers and students regarding noise distractions. The questionnaire aimed to understand how noise played a role in daily school activities. Students and teachers ranked teacher lecture, exams, and individual student reading as the activities that they felt were most affected by noises within and outside of the classroom. In an additional study, measurements and questionnaires revealed that the noise that impairs classroom activities also comes from the inside the classroom itself, not only from adjacent classrooms, halls or schoolyards. Student movement inside the classroom meant students shifting in their seats, arranging tables to move in small groups, and squeaky desk or chairs. These results demonstrate the need for noise control in these environments in order to align them with the requirements of good educational practice (Zannin 2012).

RESEARCH METHODS

We surveyed St. Olaf students in order to precisely understand the perceptions and experiences Oles had with lighting and acoustics in formal classrooms. We began our research with a focus group of 10 people. These 10 individuals were homogenous in that they were all full-time, currently enrolled students. However, each student was known by at least one researcher and the focus group members were not randomly chosen. We used a focus group to gain a basic understanding of students' awareness and concern with the lighting and acoustics found in their classroom. With this information we were better able to construct our survey to fit the concerns of both the students and our client. Our class's survey measured five aspects of formal learning spaces: Furnishings, Layout, Decor, Technology, and Lighting and Acoustics. Our team's portion of the survey focused on general aspects of lighting and acoustics and specific aspects pertaining to the student's first or third class of the week. For acoustics, we asked how satisfied students were with hearing different elements in the classroom such as films, the professor, and other students, and how often the student was distracted by different noises such as construction, other classrooms, and noises from the building itself. In reference to lighting, we asked students how distracted they were with things such as flickering lights, glare on the white/blackboard, dead bugs in the light fixtures, etc, as well as what types of lighting they preferred for various activities such as group work, watching films, and listening to lectures.

Our population was the St. Olaf student body, approximately 3,200 students, excluding students who had participated in our focus groups and students who had already taken a different survey during the semester. We also excluded questions regarding labs (science or language) and spaces where spatial physical movement courses are held because these spaces differ too much from standard classrooms. Of the respondents, 62% were female and 38% were male. Students were given 6 days to complete the survey and had the chance to win one of six potential incentive prizes. We achieved a response rate of 38% (285/750).

To assess the quality and effectiveness of classroom lighting and acoustics in meeting student and faculty needs, optimizing student engagement, and minimizing distractions, we measured perceived lighting illumination intensity (brightness), level of satisfaction with acoustics, and degrees of audio / visual distraction. Independent variables firstly included which classroom students were assessing: that of their first or third class of the week, depending on last name. Other independent variables included specific type of activity being assessed. For example, level of satisfaction with classroom acoustics depended on both the classroom in question and classroom context or purpose, including hearing professors through microphones versus hearing other students during small group work.

We measured using ordinal Likert scales with five, six, four, and, four options, respectively. We measured five levels of perceived brightness: far too dim, somewhat too dim, just right, somewhat too bright, and far too bright. A “not applicable” option was foregone; all classrooms require lighting of some sort. This was followed by a conditional, open-ended question asking for the perceived cause of excessive dimness or brightness if applicable, in order to diagnose classroom lighting issues more specifically. Across four independent variables for different classroom purposes, six levels of acoustic satisfaction were measured: very satisfied, somewhat satisfied, neutral, somewhat dissatisfied, very dissatisfied, and not applicable. In order to find solutions, this question was followed by an open-ended question asking what changes might improve classroom acoustics. Levels of distraction included four independent variables (specific noises) and four options: Very distracted, somewhat distracted, not distracted, and N/A for those who had never heard the noises in question. Lastly, lighting distractions included eight variables (potential distractions) and four options: very distracting, somewhat distracting, not distracting, and not applicable, for lighting elements that do not exist in the room in question. We used nominal measures of class year, major/majors, concentrations, gender, whether or not students were international, and racial / ethnic category. We used an ordinal measure of highest level of parental or guardian education. We also used an ordinal measure of grade point average based on a grouped 4.0 scale.

We assured face and content validity for all questions through peer and instructor consultation and feedback including pretesting, as well as through our peer focus group. Reliability of methods was ensured via direct engagement (survey promotion tables outside Stav Hall during the response period) as well incentives including St. Olaf Bookstore and Amazon.com gift certificates (Neuman 1997).

Our target population was St. Olaf students and faculty that have daily experiences with classroom settings. We chose this target population because classrooms are designed with them in mind to create a positive learning and teaching environment. Our purpose is to identify aspects of St. Olaf classrooms that hinder and/or enhance this.

Our main ethical concerns were to ensure the privacy and informed consent of our respondents. This was guaranteed through the anonymity of the survey itself, in which we had no way of connecting certain responses to specific individuals. We also provided a small introduction before the survey in which we told the participants that informed consent was given by their participating in the survey. The ethical design of our research was approved by the St. Olaf College Institutional Review Board.

RESEARCH RESULTS AND DISCUSSION

We investigated students' levels of satisfaction with the quality of lighting and acoustics and their levels of distraction by lighting and acoustic elements in classrooms. The first section below presents the results and discussion for our research question on classroom acoustics, followed by a second section with results and discussion for our research question on lighting in classrooms.

Question 1: How satisfied are students and faculty with the acoustics in their classrooms and what aspects of acoustics do students and faculty find distracting?

Acoustic Satisfaction

Of the 285 students who responded to a question regarding acoustic satisfaction, the majority reported being satisfied with the acoustics in their classroom. As shown in Table 1, combining the response categories of very satisfied and somewhat satisfied, 90.0% of respondents were satisfied with hearing their professor's voice unamplified, 85.4% were satisfied with hearing their professor when they used a microphone, 91.1% were satisfied with hearing videos, music, and other audio technology, and 85.5% were satisfied with being able to hear their peers when working in a small group.

Table 1: Level of student satisfaction with specific classroom acoustics

Response category	Very satisfied	Somewhat satisfied	Neutral	Somewhat dissatisfied	Very dissatisfied
Hearing the professor (unamplified)	75.0%	15.0%	5.4%	3.8%	0.8%
Hearing the professor (with microphone)	74.5%	10.9%	14.5%	0.0%	0.0%
Hearing videos, music, and other audio technology	68.9%	22.2%	6.1%	1.4%	1.4%
Hearing the other students in my small group while working with them in class	61.7%	23.8%	8.1%	5.2%	1.2%

*See Appendix A for an expanded version of this table that include frequencies.

We conducted bivariate analysis and compared each possible response category across gender and class year but found no statistically significant results.

Our survey also asked students what changes would help improve acoustics (regardless of their level of satisfaction) in their selected classroom. Students reported that the sound system in classrooms is inconsistent, because professors did not know how to adjust the volume, because the sound system was difficult to control (2 students), or because the microphones and speakers would unexpectedly stop working (3). Students were also distracted because of noise coming from outside the building (1) and inside the building, such as people talking in the hallways (1), ventilation (1), fans (1), loud AC (1) or "random" [sic] building noises (1). Students suggested updating and upgrading the equipment, in particular the speakers (10) and the microphones (1) as well as training the professors to use the equipment (1). Students also suggested minimizing echoes with carpets (1) and by building thicker walls to minimize noise from the outside (1). See Appendix C for specific acoustic suggestions and their corresponding classroom.

While there is a shortage of literature on acoustic satisfaction and its connection to learning, Zannin (2012) found that when classrooms were located near high levels of noise traffic (for example, classrooms adjacent to main thoroughfare hallways), the most affected classroom activities were teacher lectures, exams, and individual student reading (Zannin 2012). This is in alignment with our findings that students were most distracted when they were unable to hear their professor well, either because of poor acoustical equipment or noises that distracted them from learning.

These results suggest the following recommendations:

- Classrooms should be upgraded with easy-to-use speaker systems that can be heard throughout the classroom (surround sound)
- Classrooms that are near hallways and/or the outside should have thicker insulation or noise barriers to block out exterior noises
- Minimizing interior building noises, such as ventilation or fans, to decrease distractions in the classroom

Acoustic Distractions

A total of 258 respondents answered a question regarding acoustic distractions in specific classrooms. They noted whether noises from outside, hallways, student movement, and/or from the building itself distracted from their learning experience while in class (as listed in Table 2 below). For each of the noise categories listed, approximately one-fifth to one-fourth of respondents reported being distracted during class.

Table 2: Level of distraction during class due to types of noise sources

Specific acoustic distraction	Yes, I have been very distracted by this.	Yes, I have been somewhat distracted by this.	I've heard these noises but they have not distracted me.	I have not heard these noises.
Noises from outside	7.2%	14.8%	21.7%	56.3%
Noises from people in the hallways	5.4%	21.9%	34.2%	38.5%
Noises from students moving in the classroom	2.7%	16.1%	60.9%	20.3%
Noises from the building (pipes, fan, projector, buzzing lights, etc.)	5.0%	14.6%	32.3%	48.1%

*See the Appendix A for an expanded version of this table that include frequencies.

Zannin's (2007) study of the quality of acoustics in classrooms conducted a survey of teachers and students to identify the quality of acoustics in classrooms. In the study, students and teachers indicated that one main source of distraction was due to the voice of neighboring teachers. Our survey did not ask specifically about noises from neighboring classrooms, but we did ask a similar question about noises from people in the hallways. Of the respondents, about a quarter were distracted by this noise. In Zannin's study, teachers and students also indicated that one of the main sources of distractions came from the classroom itself, such as student movement and squeaky furniture. In our study, we asked students to rate their level of distraction with noises attributed to students moving in the classroom. A combined total of 79.7% of students reported that they have heard this noise, which is consistent with Zannin's findings. However, only 18.8% (a combination of “very distracted” and “somewhat distracted”) of those that have heard noises from student movement have been distracted by it. Our study did not ask students to rate their level of distraction attributed from other sources of acoustics inside the classroom, such as from squeaky furniture.

In comparison, a smaller percentage of respondents, 61.5%, indicated hearing noises from people in the hallways during class, but a larger percentage, 27.3%, reported being distracted by this. Further, 51.9% of respondents have heard noises from the building itself (such as buzzing lights, pipes, fan), but only 19.6% report being distracted by these noises. Also, 43.7% reported hearing noises from outside the building, with 22% being distracted by this. We created a 16-point index that summed scores on the four categories of acoustic distraction listed on Table 2. The mean level of distraction is 7.45, which suggests that, on average, students perceive a low level of distraction from the acoustic categories we asked about.

We compared the means from the Student Level of Acoustic Distraction index across categories of race/ethnicity (white and racial/ethnic minority), and found a difference. The mean level of acoustic distraction for white respondents was 8.18 and the mean for racial/ethnic minority respondents was 7.54. To test whether the mean difference was statistically significant, we ran an independent samples t-test. We found no significance ($U=3150$, $p>.05$). Although not statistically significant, the respondents that self-identified as racial minorities tend to report a higher level of acoustic distractions and this difference implies that racial minorities may be more distracted with the acoustic categories in question compared to their white counterparts.

Because a high percentage of respondents, one-fifth to one-fourth, reported being distracted during class, we recommend improving noise ambience by allowing little to no noise penetration into classrooms. Zannin (2012) reported that six of the schools under investigation for building standards had low noise levels. Low noise levels were largely due to the sound insulation of both facades and dividing walls. These types of dividers allowed for a separation between classrooms and between hallways and classrooms. Thus, this noise prevention reduced noise saturation into school classrooms.

Question 2: What type of lighting do students prefer for specific activities in formal learning spaces (e.g., for lectures, group discussions, exams, presentations, movies, etc.)?

Lighting in Selected Classrooms

When asked to rate the brightness or dimness of the lighting in their classrooms (again, we used a system to direct students to answer about one of their specific classrooms), a large majority of respondents reported that the lighting is “just right” (85.9%), as shown in Table 3. Those who reported otherwise were more likely to report that the lighting was too bright (9.5%, combining somewhat and far too bright) rather than too dim (4.6%). Of these students, most indicated that lighting was only somewhat too bright. For a list of specific classrooms and student assessment of their brightness/dimness, see Appendix B.

Table 3: Quality of lighting in a selected classroom

Response category	Percentage	Frequency
Far too bright	0.8%	2
Somewhat too bright	8.7%	23
Just right	85.9%	226
Somewhat too dim	4.6%	12
Far too dim	0.0%	0

We asked students who reported classrooms as too bright or too dim to elaborate on what caused this. Of the 41 students who responded, seven addressed classrooms that were too dim, with four stating that there was too little natural light and two stating that the classroom was too dim because of too little artificial light. Of the 22 students who discussed classrooms that were too bright, 11 attributed this to the use of too much artificial light, with five noting the concurrent lack of natural light and only two reporting too much natural light. As one student described:

> There is a lot of natural light in the classroom, and depending on the point in the day it ranges from being too bright to too dim. The shutters don't block out enough light when used and take a long time to close, taking up a large amount of class time if we're trying to view something on the projector. The fluorescent lights are very abrasive, so the majority of people using the space typically do what they can to avoid using them.

This quote corresponds with the growing literature on lighting and learning. Research has shown that while a combination of natural and artificial lighting is important, it is even more important that the two can seamlessly be adjusted to the desired lighting preference (Davis 2012).

In alignment with our literature and data on classrooms and bright or dim lighting, we suggest that flexibility is essential to successful learning when lighting is involved in the classroom. We recommend a combination of natural light (with easy-to-operate blinds/curtains) and controllable artificial lights (lights that can be turned on and off in groups and lights that can be dimmed or brightened to preference) can help combat the issue of brightness in the classroom.

Lighting Distractions in Selected Classrooms

We asked students about the level of lighting distractions in classrooms. One question asked specifically about the following distraction: mismatching lights, flickering lights, bugs in the lights, glare from projector screens and black or whiteboards, glow from electronic devices, and light switch and control options.

As shown in Table 4, students who observed potential light distractions were most likely to report being distracted by flickering lights and glare on the projector screen: 73.1% found flickering lights distracting (36.1% very distracting, 37.0% somewhat distracting) and 64.8% found glare distracting (20.6% very distracting, 44.2% somewhat distracting). This aligns with studies that found flickering lights and glare decrease overall student performance (Mott 2012).

Table 4: Level of distraction due to lighting

Specific lighting distraction	Very distracting	Somewhat distracting	Not at all distracting
Lights that don't match (different on color or intensity, etc.)	12.7%	30.5%	56.8%
Lights that flicker	36.1%	37.0%	26.9%
Bugs in the lights	16.3%	34.1%	49.6%
Glare on the projector screen (e.g., from overhead or natural light)	20.6%	44.2%	35.2%
Glare on the blackboard or whiteboard	17.1%	36.6%	46.3%
Glow from other students' electronic devices (computers or hand-held devices)	5.3%	20.5%	74.2%
Light switch options that don't make sense for the room (For example, it is not possible to turn lights near the screen down or off without turning off all of the lights)	7.3%	24.5%	68.2%
Light controls that are confusing or difficult (For example, it is hard to quickly turn the lights on or off or to dim them.)	8.2%	25.7%	66.1%

*See Appendix A for an expanded version of this table that include frequencies.

We created an index for lighting distractions using all eight items in Table 4. We compared the means from this index across gender (male and female) and across race/ethnicity (white and racial/ethnic minority), and found differences among our respondents but did not find statistical significance. The mean level of lighting distraction for males was 19.00 and the mean for female was 17.59. However, a Mann-Whitney U test found no statistically significant difference ($U= 331.000$, $p>.05$). Male students do not tend to be more or less distracted by lighting issues than females. The mean level of lighting distraction for "white" respondents was 17.74 and the mean for "racial-ethnic minority" was 19.15. However, a Mann-Whitney U test found no statistically significant difference between the two groups ($U=196.000$, $p>.05$). White students do not tend to be more or less distracted by lighting issues than racial-ethnic students.

These results regarding lighting in classrooms suggest the following recommendations:

- Design classrooms with more windows to increase natural lighting and decrease dependency on artificial lights (eliminating chances of flickering lights).
- Design classrooms with light fixtures on walls so that they are more accessible, making it easier to switch light bulbs.
- Design classrooms with window blinds to avoid glare on the projector screen.

Lighting Preference for Specific Activities, Across Classrooms

We also asked students whether natural or artificial (electrical) lighting works best for each of the following classroom activities: group work, individual work, presentations such as PowerPoints, films or video clips, lectures, and exams. Overall, the vast majority (90.5%) prefer at least some natural light. Of all the responses who indicated a preference for lighting type, the plurality preferred a combination of natural and artificial light (45.5%), while fewer preferred natural light only (34.6%) and the fewest number of students preferred artificial light only (19.9%). However, these numbers vary depending on the specific activity in question (Table 5). A majority of students prefer a combination of natural and artificial lighting for all activities except for those using projectors.

Table 5: Preferred Type of Lighting for Selected Classroom Activities

Activity	Artificial lighting	Combination of natural and artificial lighting	Natural lighting
Group Work	4.4%	58.3%	37.3%
Individual Work	9.4%	50.2%	40.4%
Presentations with PowerPoint or other screen use	40.4%	29.1%	30.5%
Films, movies, videos, etc.	40.9%	24.1%	35.0%
Lectures	11.2%	55.6%	33.2%
Exams	14.5%	54.8%	30.8%

Of students reporting a preference, the majority prefer a combination of natural and artificial lighting for group work in classrooms (57.8%) while fewer prefer natural lighting only (37.8%) and fewer still artificial lighting only (4.4%). The vast majority (85.4%) prefer at least some natural lighting in their classrooms when doing group work, as shown in Figure 1.

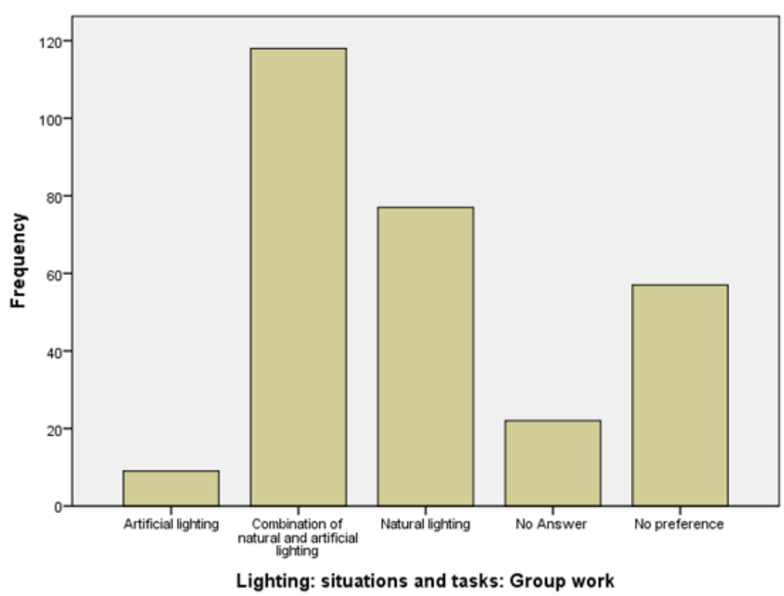

Figure 1. Student lighting preference for group work during class

Results are similar for individual work, with about half (50.2%) of respondents preferring a combination of natural and artificial light , a large minority (40.3%) preferring natural lighting alone , and only a small minority(9.5%) preferring solely artificial light, and the vast majority (90.5%) preferring at least some natural light. Respondents also preferred a combination of natural and artificial light for lectures (55.7%) and for exams (54.8%). However, this does not hold true for classroom activities requiring projector use, including presentations with PowerPoint as well as films, movies, and videos. These results were split relatively evenly: among students indicating a lighting preference for presentations, 39.8% prefer artificial lighting only while fewer (30.8%) prefer natural lighting and 29.4% prefer a combination. For films, movies, and videos, 40.8% of respondents indicated a slight preference for artificial lighting while fewer (35.3%) preferred natural lighting and the fewest (23.9%) preferred a combination.

The preference for natural lighting over artificial lighting in our results mirrors findings from Cobham's 2013 study, in which students whose current classrooms lacked windows, when asked to draw their ideal classroom, drew rooms with a high number of windows. The deviation from this preference for natural light during activities requiring electronic media resources, such as PowerPoints or films, also highlights the need for lighting flexibility in classrooms. Our results reflect similar findings as both Cobham (2013) and Sleegers (2012), who found that student distraction decreases when teachers have the ability to choose between different types of classroom lighting, even including controls for lighting warmth and intensity. However, open-ended responses also note the importance of instructor competence with technology. Classroom design should incorporate flexible lighting technologies with various options, but should be designed in a user-friendly way, as technological consistency matters more in practice than potential technological capabilities.

Our results suggest the following recommendations:

- Design classrooms with both windows and electrical lighting sources
- Include controls for lighting flexibility when designing classrooms, including dimmers for electric lights and easily-operable blinds for windows

Final Suggestions from Respondents: Lighting and Acoustics

At the end of our survey, we asked students to tell us anything else they had to say about lighting or acoustics in the classroom. Though relatively few students responded, some had helpful suggestions or ideas. Many students confirmed a general preference for natural light, specifically suggesting it for Old Main and Tomson halls. Others thought natural light made them more focused or relaxed. One student stated: “Natural light is best, but it has limitations, especially on gray days.” However, other students reiterated the importance of control and versatility. For example, one student enjoyed natural light, but wanted an easy way to pull the blinds to limit glare from sunlight. Another student stated that buzzing lights were very distracting and made pauses in conversation awkward (sic). In regards to dimness, one student stated that the lecture rooms were too dim, while one preferred darker rooms overall and another preferred dark classrooms when viewing films. No students had any further suggestions regarding acoustics.

CONCLUSION AND RECOMMENDATIONS

Our research focused on student and faculty levels of satisfaction and distraction with classroom lighting and acoustics as well as lighting type preference.

We found that about one out of five students was distracted by classroom acoustics. Most distracting were noises coming from inside the classroom but also distracting were noises coming from ambient building noise such as air circulation as well as noise coming from outside of rooms such as construction or hallway noise. These findings highlight the need to incorporate acoustic isolation and dampening throughout the classroom design process.

Students also generally rated their classrooms as appropriately bright. Those who rated classroom brightness as anything other than “just right” were more likely to rate classrooms as too bright than as too dim. Open responses to this question indicated that natural light can vary throughout the day, changing brightness or dimness and necessitating the need for lighting control strategies and technologies such as blinds for natural lighting and dimmers for artificial lighting.

Further, aspects of lighting that distracted students the most included glare on projector screens and white/blackboards as well as flickering lights. To alleviate these potential distractions, classrooms should be designed with ample natural lighting and wall-mounted, easily accessible lighting fixtures should be used.

We found that students generally prefer a combination of natural and artificial classroom lighting for most activities but that for activities requiring a projector, students prefer artificial lighting only. Otherwise, students demonstrate a slight preference for natural over artificial lighting. While this emphasizes the need for natural lighting in classrooms, perhaps more important is the need for instructor and student control over lighting type.

Due to the limited scope of our study, we are unable to extrapolate our findings beyond St. Olaf College, our predominantly non-Hispanic white, liberal arts college demographics, and the slightly female-skewed gender balance of our sample. Moreover, our study only assesses perceived student satisfaction, distraction, and preference, and cannot definitively determine actual level of lighting and acoustic effectiveness and student learning engagement.

Based on our research, we offer three recommendations:

1. Incorporate acoustic insulation strategies such as dampening and soundproofing to minimize both exterior and interior noise.
2. Design classrooms with both windows and electrical lighting. Incorporate controls to make a combination of natural and artificial light easy to control and flexible to adjust.
3. Design classroom lighting to be able to accommodate a variety of classroom activities by incorporating lighting control that can turn off specific lights rather than all lights or no lights.

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APPENDIX A

Complete satisfaction and distraction tables, with counts.

Table 1 (expanded): Level of student satisfaction with specific classroom acoustics

Response Category	Very satisfied	Somewhat satisfied	Neutral	Somewhat dissatisfied	Very dissatisfied
Hearing the professor (unamplified)	75.0% (195)	15.0% (40)	5.4% (14)	3.8% (10)	0.8% (2)
Hearing the professor when using a microphone	74.5% (41)	10.9% (6)	14.5% (8)	0.0% (0)	0.0% (0)
Hearing videos, music, and other audio technology	68.9% (146)	22.2% (47)	6.1% (13)	1.4% (3)	1.4% (3)
Hearing the other students in my small group while working with them in class	61.7% (153)	23.8% (59)	8.1% (20)	5.2% (13)	1.2% (3)

Table 2 (expanded): Level of distraction due to types of noise, with percentages and frequencies

Specific acoustic distractions	I have not heard these noises.	I've heard these noises but they have not distracted me.	Yes, I have been somewhat distracted by this.	Yes, I have been very distracted by this.
Noises from outside	56.3% (148)	21.7% (57)	14.8% (39)	7.2% (19)
Noises from people in the hallways	38.5% (100)	34.2% (89)	21.9% (57)	5.4% (14)
Noises from students moving in the classroom	20.3% (53)	60.9% (159)	16.1% (42)	2.7% (7)
Noises from building (pipes, fan, projector, buzzing lights, etc.)	48.1% (125)	32.3% (84)	14.6% (38)	5.0% (13)

Table 4 (expanded): Level of distraction with lighting

Specific lighting distractions	Very distracting	Somewhat distracting	Not at all distracting
Lights that don't match (different on color or intensity, etc.)	12.7% (15)	30.5% (36)	56.8% (67)
Lights that flicker	36.1% (43)	37.0% (44)	26.9% (32)
Bugs in the lights	16.3% (21)	34.1% (44)	49.6% (64)
Glare on the projector screen (e.g., from overhead or natural light)	20.6% (34)	44.2% (73)	35.2% (58)
Glare on the blackboard or whiteboard	17.1% (28)	36.6% (60)	46.3% (76)
Glow from other students' electronic devices (computers or hand-held devices)	5.3% (7)	20.5% (27)	74.2% (98)
Light switch options that don't make sense for the room (For example, it is not possible to turn lights near the screen down or off without turning off all of the lights)	7.3% (8)	24.5% (27)	68.2% (75)
Light controls that are confusing or difficult (For example, it is hard to quickly turn the lights on or off or to dim them.)	8.2% (9)	25.7% (28)	66.1% (72)

APPENDIX B

The following table shows how students rated the lighting intensity of the classroom that their first class is in (ranging from far too bright to far too dim). 37 students reported that their classroom was not just right and their answers are organized below by specific buildings.

Key			
BC	Buntrock Commons	RML	Rolvaag Memorial Library
BMC	Boe Memorial Chapel	RNS	Regents Hall of Natural Sciences
CHM	Christiansen Hall of Music	SAC	Skoglund Athletic Center
DC	Dittmann Center	TB	Theater Building
HH	Holland Hall	TOH	Tomson Hall
OM	Old Main		

*Insufficient data (respondents that answered, but didn't put what classroom they were talking about or people who put a class down, but didn't answer the question) has been omitted.

Classrooms reported as far too bright:
- CHM 233
- RML 252

Classrooms reported as somewhat too bright:
- CHM 224, 232, 345
- HH 501
- OM 110
- RML 515, 520 (2)
- RNS 190, 204, 210, 255, 290, 390, 410
- TB 216
- TOH 108, 112, 212, 280, 308, 310, 314

Classrooms reported as somewhat too dim:
- DC 305
- HH 403, 501, 514, 516
- OM 020 (2), 110, 340
- RNS 190, 310
- TOH 280

Table 6: Quality of lighting in specific classrooms (Total list)

Light Intensity	Room	Light Intensity	Room	Light Intensity	Room
Far too bright	CHM 233	Just right	RNS 208	Just right	RNS 290
Far too bright	RML 525	Just right	RML 501	Just right	DC 202
Somewhat too bright	TOH 280	Just right	HH 317	Just right	OM 310
Somewhat too bright	RNS 255	Just right	TOH 214	Just right	HH 301
Somewhat too bright	RML 520	Just right	RNS 310	Just right	CHM 232
Somewhat too bright	TOH 212	Just right	HH 319	Just right	RNS 410
Somewhat too bright	TB 216	Just right	RNS 310	Just right	RML 420
Somewhat too bright	CHM 232	Just right	TOH 114	Just right	HH 319
Somewhat too bright	TOH 112	Just right	RML 525	Just right	RNS 190
Somewhat too bright	RNS 204	Just right	TOH 184	Just right	TOH 314
Somewhat too bright	RNS 390	Just right	RNS 297	Just right	TOH 310
Somewhat too bright	RNS 210	Just right	TOH 312	Just right	HH 516
Somewhat too bright	OM 110	Just right	TOH280	Just right	RNS 310
Somewhat too bright	CHM 345	Just right	RNS 210	Just right	TOH 212
Somewhat too bright	TOH 308	Just right	TOH 108	Just right	DC 305
Somewhat too bright	HH 501	Just right	RNS 435	Just right	TOH 116
Somewhat too bright	RNS 290	Just right	RNS 290	Just right	HH 403
Somewhat too bright	RML 515	Just right	RNS290	Just right	TOH 316
Somewhat too bright	CHM 224	Just right	OM 210	Just right	CHM 239
Somewhat too bright	TOH 310	Just right	RML 515	Just right	RNS 210
Somewhat too bright	TOH 314	Just right	RNS 190	Just right	HH 403
Somewhat too bright	RNS 190	Just right	RNS 203	Just right	RNS 390
Somewhat too bright	TOH 108	Just right	HH 302	Just right	HH 403
Somewhat too bright	RNS 410	Just right	TB Green Room	Just right	Phys 112
Somewhat too bright	RML 520	Just right	RNS 208	Just right	TOH 186
Just right	OM 010	Just right	OM 010	Just right	TOH 186
Just right	TOH 310	Just right	RNS 310	Just right	TOH 110
Just right	RML 520	Just right	OM 030	Just right	TOH 108
Just right	TOH 184	Just right	RML 421	Just right	HH 317
Just right	RNS 190	Just right	DC 305	Just right	RNS 203
Just right	TOH 280	Just right	RNS 310	Just right	RNS 210
Just right	RML 515	Just right	TOH 280	Just right	RML 421
Just right	TOH 212	Just right	OM 110	Just right	RNS 206
Just right	TOH 300	Just right	TOH 214	Just right	RML 520
Just right	HH 501	Just right	TOH 300	Just right	TOH 212
Just right	TOH 280	Just right	TOH 110	Just right	HH 514
Just right	RNS 290	Just right	RNS 202	Just right	RNS 210
Just right	CHM 224	Just right	DC 305	Just right	TOH 314
Just right	OM 110	Just right	RNS 290	Just right	TOH 114
Just right	TOH 108	Just right	HH 403	Just right	OM 210
Just right	TOH 108	Just right	SAC 203	Just right	RNS 210
Just right	HH 302	Just right	HH 319	Just right	TOH 153
Just right	TOH 280	Just right	BMC 221	Just right	OM 310
Just right	TOH 210	Just right	RNS 210	Just right	BC 202
Just right	RNS 310	Just right	TOH 182	Just right	RNS 210
Just right	OM 110	Just right	HH 403	Just right	RNS 190
Just right	TOH 310	Just right	HH 515	Just right	OM 210
Just right	RNS 210	Just right	HH 515	Just right	TOH 280
Just right	RNS 410	Just right	RNS 390	Just right	RNS 400
Just right	HH 301	Just right	RNS 410	Just right	TOH 310
Just right	RNS 410	Just right	RNS 124	Just right	CHM 239
Just right	TOH 214	Just right	HH 516	Just right	TOH 210
Just right	TOH 108	Just right	TOH 280	Just right	RNS 190
Just right	OM 210	Just right	HH 301	Just right	HH 317

Just right	RNS 206	Just right	RML 421	Just right	OM 310
Just right	RNS 410	Just right	OM 140	Just right	RNS 210
Just right	TOH 280	Just right	TOH 186	Just right	HH 403
Just right	RNS 210	Just right	HH 319	Just right	DC 204
Just right	RNS 210	Just right	TOH 212	Just right	OM 210
Just right	HH 307	Just right	HH 501	Just right	RNS 356
Just right	BMC 202	Just right	RNS 290	Just right	TOH 308
Just right	TOH 280	Just right	TOH 316	Just right	OM 240
Just right	TOH 312	Just right	TOH 316	Just right	TOH 300
Just right	RNS 290	Just right	RNS 190	Just right	HH 403
Just right	RNS 290	Just right	CHM 232	Just right	RNS 204
Just right	RML 525	Just right	RNS 410	Just right	RNS 150
Just right	TOH 310	Just right	TOH182	Just right	RNS 310
Just right	RNS 410	Just right	RML 525	Just right	OM 020
Just right	TB 227	Just right	RNS 210	Just right	RNS 208
Just right	RNS 203	Just right	OM 301	Just right	HH 301
Just right	HH 403	Just right	HH 413	Just right	RNS297
Just right	RNS 208	Just right	TOH 312	Just right	RNS 410
Just right	RNS 208	Just right	RNS 208	Just right	RML 420
Just right	RNS 208	Just right	RNS 410	Just right	TOH 280
Just right	RNS 310	Just right	CHM 233	Just right	TOH 308
Just right	RNS 297	Just right	TOH 182	Just right	RNS 190
Just right	OM 010	Just right	OM 210	Just right	OM 010
Just right	RML 515	Just right	OM 030	Just right	RNS 435
Just right	OM 340	Just right	RNS 310	Just right	OM 240
Just right	HH 403	Just right	OM 210	Just right	HH 512
Just right	RNS 150	Just right	RNS 208	Just right	HH 403
Just right	TOH 182	Just right	RNS 208	Somewhat too dim	OM 110
Somewhat too dim	OM 020	Somewhat too dim	RNS 310	Somewhat too dim	OM 020
Somewhat too dim	HH 514	Somewhat too dim	HH 501	Somewhat too dim	RNS 190
Somewhat too dim	OM 340	Somewhat too dim	TOH 280	Somewhat too dim	DC 305
Somewhat too dim	HH 403	Somewhat too dim	HH 516		

APPENDIX C

Student comments on what aspects of each classroom were affecting their overall acoustic satisfaction. *(Refer to Appendix B for building abbreviations key)*

- Sound system (microphone and speakers) was difficult to control (2): RML 420, RNS 190
- Sound system (microphone and speakers) unexpectedly stopped working (2): 280 TOH, RNS 290
- Updating and upgrading the speakers for better sound quality (10):
    - CHM: 232 (2), 239,
    - RNS: 190, 208, 210, 290, 410
    - TOH 108, 308
    - Updating and upgrading the microphone (1): 020 OM
- Distracting noises from inside the building (5):
    - People talking in the hall: RNS 410
    - Ventilation: RNS 202
    - AC: TOH 280
    - Fans: RNS 203
    - *Random* [sic] building noises: TOH 214
    - Distracting noises from outside the building (1): HH 413
    - Minimizing echoes with the use of carpets (1): HH 403
    - Thicker walls to eliminate noise from the outside of the building (1): HH 413