METHOD OF IMAGES AND INFLUENCE OF LIGHTING RADIATION INTENSITY ON STUDENT LEARNING EFFECTIVITY IN HYGIENE AND ERGONOMICS OF EDUCATION

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One day, in early childhood, I attended a performance of a virtuoso counter. He very quickly made mental calculations on the stage, multiplying millions, taking the roots of the thirteenth degree, etc. After the end of the speech, I approached him and asked, looking upwards how he did it. He smiled and said that everything was built solely on natural abilities. Much later, while studying in high school, I read an interview in one of the magazines explaining that when he saw large numbers, he presented their image in the form of a color carpet, where each digit is represented in a certain color. In the process of calculating the light colors flicker, and as a result, a new carpet appears, representing the final result. It remains only to consider the answer, turning it back into numbers. This revelation led me to a deeper study of the issue.

I found out from literature that Isaac Newton, Galileo Galilei, Richard Feynman, Vladimir Nabokov, Ferenc Liszt, Nikolai Rimsky-Korsakov, Duke Ellington, Alexander Scriabin and many scientists used images of digital-color analogies.

They were further summarized in various writings of Bulat Galeyev on color music. I decided to build a calculator, and later a computer, based on digital-light-color analogies and supplement it also with sound ones [1]. I tested it on classmates, relatives, acquaintances and on my father, a marine officer, who by that time had a number of patents and made a number of inventions to improve the performance of the machine gun.

Much later, when I was already a college student in semiconductors, I met with psycho-physiologists and ergonomists from the Tupolev Design Bureau. We collected 5 groups of 30 people each and began to conduct experiments to study the effect of light, color and sound on the speed and accuracy of working with information. [2-5]

The statistically reliable results obtained by psychologists during the processing of Anfimov's correction tables (analogy of brickenkamp d2 test of attention, Bourdon Tests, etc.) surpassed all expectations: the speed of calculation of control samples of the test material increased significantly with the use of light-color-sound analogies and the number of errors decreased.

It turned out that image representations of numbers in combination of light-color-analogies significantly affect the results.

Indeed, compare the technique of multiplying the numbers represented by Arabic numerals, so familiar to us, with the multiplication of Roman numerals. Did you try to multiply the two numbers represented by Roman numerals? We formulate a hypothesis and tested, conducting research that digital-light-color analogies helpful in the calculations. Based on these researches we created Method of Images for teaching Math and any subject [1-8].

We tested the Method in schools and universities 19 years before it was applied around the world and in 1993 extensively was used in USA. In 1993 we created the best test prep for Science, Math and Creative writing for Elite Junior High Schools and High Schools, our method of teaching and studying Science, Math has demonstrated highest passing rates over the 42 years and has shown amazing results. Moreover, given the modern achievements of ergonomics, the scientific organization of labor, physiology and biomechanics, we were able to make the method work perfectly in all groups and audiences. We successfully applied Method of Images in teaching various subjects: TRIZ (theory of inventive problem solving), dynamics, programming, biomechanics, organic and non-organic chemistry, pharmacology, chemistry of natural compounds, organic chemistry, medical chemistry, pharmaceutical chemistry, analytical chemistry, toxicological chemistry, pharmacognosy, drug technology, botany, pathological physiology, pathological anatomy, physical chemistry, biophysics, biochemistry, biotechnology, microbiology, immunology, virology, plant medicine technology, marketing and management of pharmaceutical and chemical production, commodity research, logistics, and many others. We have got set of patents and done set of presentations. The method was successfully applied for preparation students from the Olympic team, for preparation students for admission tests for top rated university, and for improving students results in schools for Math and Science Olympics. Our students have got the highest scores and one of the highest success rate in Math, Science, English in passing to Elite Junior High Schools (e.g. Mark Twain, Bay Academy etc.) and Elite High Schools Such are Stuyvesant, Long Island and Brooklyn Tech, etc., since 1993 [6-8]

We applied the Method for teaching TRIZ (theory inventive problem solving) and even saw success in teaching blind-def-mute students based on our vibro- tactile technologies as well. For improvement results of students, we studied impact of light, color and sound analogies for developing analytical thinking skill. So, we have created a unique course of study with "know-how", based on the Method of images, which allows us to develop top analytical thinking skill and think systematically.

To educate children on the Image Methodology, we invited scientists from different countries, including Professor D. Manzini, a scientist from Switzerland, who has extensive scientific and pedagogical experience. The program is replete with wonderful experiments that accompany lectures conducted in a fascinating manner,

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which allows you to better understand the basic concepts of mathematics, the subject of Science and love them.
Meanwhile, another factor that could have result for student learning efficacy could be environment, including influence of lighting radiation intensity. We decided to conduct research "influence of lighting radiation intensity on student learning effectivity on base of Farber's Center for Academic Success and Saratoga Waldorf School."

To understand our study a brief background information on lightning is necessary. A fluorescent light bulb made from a glass tube filled with mercury in a gaseous state at low pressure. When an electric current is applied to the gas inside the glass tube the mercury vapors become ionized. This causes electrons in the gas to emit photons with the frequency of the UV electromagnetic waves. The UV light is converted into standard visible light using phosphorus coating inside the glass tube that starts to glow [9]. This phenomenon is called fluorescence. The last generation of fluorescent lamps had a a coiled or folded shaped the size of a regular incandescent light bulb. In the base of the lamp they have electronic ballast, which is a device that uses semiconductors to limit electrical power to the fluorescent lamp. This device makes the fluorescent more expensive than incandescent light bulbs, but the cost is recuperated over time through energy efficiency [10]. A light-emitting diode (LED) uses semiconductors to create light by electroluminescence [11]. Electroluminescence is the phenomenon of a material to emit light when electric current is applied to semiconductor [12]. The electrons fill the electron hole of the semiconductor that is made from a pn-junction diode and releases energy in the form of photons [13]. The color of light is determined by the energy band gap of the semiconductors. The first LEDs light were tiny light bulbs used as electronic components in remote control circuits and emitted low-intensity infrared light. Modern LED lights have high brightness and they are available in visible, ultraviolet and infrared wavelength [14]. When they are collected together, they can form images on a big television screen and can be used as traffic lights, head lamps for cars, and especially as light bulbs for general lighting.

Table 1 LED compared to CFL and the incandescent light [7]

Energy Efficiency (bulbs with comparable luminosity)	**Incandescent Light Bulbs**	**Fluorescent (CFL)**	**LED**
Life Span (average)	1,200 hours	8,000 hours	50,000 hours
Watts of Electricity Used	60 watts	13-15 watts	6-8 watts
Annual Operating Cost. Statistic represents the usage of the 30 bulbs for 5 hours per day.	$361.35/year	$84.32/year	$42.16/year

There are significant differences between incandescent light bulbs, LED light bulbs and CFLs light bulbs in terms of energy efficiency, energy usage and environmental impacts, durability, and light (lumen) output [15]. For example, incandescent bulbs emit large amounts of heat which can increase air conditioning costs and energy consumption while using air conditioning. Switching a CFL on/off quickly in a closet for instance may decrease the lifespan of the bulb. As seen in the table below LED light bulb is the most energy efficient, least costly to operate, and works a longer period of time than the other two light bulbs. There is a significant difference when we compare the environmental impacts of the three light bulbs. The fluorescent (CFL) light bulbs contain mercury which is hazardous to human health. The incandescent light bulb has a five time the carbon footprint (carbon dioxide emission) of a LED light bulb.

Table 2 LED compared to CFL and the incandescent light

Environmental Impact	**Incandescent Light Bulbs**	**Fluorescent (CFL)**	**LED**
Contains toxic materials	No	Yes- Toxic for your health & the environment	No
RoHS Compliant (Reduction of Hazardous Substances).	Yes	No – contains 1mg-5mg of Mercury and is a major risk to the environment	Yes

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Carbon Dioxide Emissions (Carbon Footprint). Statistic represents the usage of the 30 bulbs for 5 hours per day and 365days/year.	4405 lbs./year	1028 lbs./year	514 lbs./year
Heat Emitted	85 BTU's/hour	30 BTU's/hour	3.4 BTU's/hour

Regarding the durability of the three light bulbs the LED bulb is the incontestable leader. LED lamps can handle jarring and bumping. The fluorescent light bulbs can break very easily releasing mercury vapors in to the environment. Also, in the case of incandescent light bulbs the glass and the filament can break very easily. The possibility of mechanical failure is not typical for LED lights, but the fluorescent light bulbs may catch on cause fire, smoke or emit an odor. While the LED and incandescent light bulbs turn up instantly, the CFL light bulbs takes time to warm up the mercury to achieve maximum light output. The on/off cycling has no effect on the LED lights, but has some effect on the incandescent light bulbs and can reduce the life span drastically for the fluorescent lights. Humidity has no effect on the LED lights, but the CFL lights can have a higher failure rate in more humid environments and there is some humidity effect on the incandescent light bulbs.

The purpose of our study was to research if the replacements of CFL light bulbs in our high school with LED light bulbs would create an improvement in students' learning during the school day for high school students at EWS. The direct relationship between good lighting and students' performance has already been proven by numerous studies. In1986, Hathaway and Fielder have found that classroom lightning in a school building is a key component for the general well-being of the students. Earlier in 1963, Blackwell also found that the effectiveness of information collection is reduced in bad light. Lexington, in 1989. and Hawkins and Lilley in 1992 performed studies showing that better lighting gives improved productivity. Other studies (King and Maran in 1979) have showed the negative aspects of fluorescent lights, like hyperactivity in children compared with incandescent lights and full spectrum lights.

Materials and methods

LED lights have entered the consumer market in the past few years but are still ignored by a large part of US population. The number of studies comparing LED lights with fluorescent lights is increasing every year, but is relatively small. This is the first study of this kind in Farber's Center for Academic Success and Waldorf schools in USA. The first question that the senior students were asking at beginning of the study was in which room should the study take place? The lab was an obvious choice, but some students suggested the faculty library as being a smaller room that could be blackened out. The second question was what type of LED light bulb we should use in our study? We asked many people in the school community who we suspected might have some expertise in this area without much success. After many hours of online searching, reading customer reviews and consumer reports we decided on even different LED light bulbs. We used suppliers who provided the most varieties of LED lights at lowest prices and the most technical details and information. **Prices of light sources also important, since many schools, test prep centers and colleges have different budgets.**

Below is a list of technical characteristics and prices of the seven LED light bulbs:

1. Philips 423798 10.5-Watt (65 Watt) BR30 Indoor Soft White (2700K) Flood LED Light Bulb, Dimmable priced at $20.97
2. Earth LED ThetaLux 9-Watt Warm White LED Light Bulb priced at $34.90
3. G7 Power G7A21930 900 Lumen LED Light Bulb, 9-watt, Warm White
4. Feit Electric Performance LED 13.5 Watt LED Omni - 60W Incandescent Dimmable Replacement Bulb priced at $13.50
5. Lighting EVER 10-Watt A19 LED Bulb, 60-Watt Incandescent Bulbs Replacement, 830lm, Samsung chip LED, Daylight White priced at $9.99
6. Feit Electric BPA15/CL/LED/RP Accent LED A15 Bulb, Clear priced at $6.97
7. Feit BPAG500DM/LED A19 Semi Omni LED priced at $13.39

After many trials in our classroom with these 7 LED light bulbs we narrowed down our choices in term of being comfortable with the light to a soft white LED light bulb produced by Feit Electric.

The winner was: Feit electric 60-Watt Equivalent Soft White Dimmable LED Item Number: BPAG1100DM/LED

Next, we compared the brightness of this LED bulb with our current fluorescent bulbs. We decided that we needed a brighter one (750 lumens given by the 60W LED light wasn't bright enough for our needs in our opinion). I

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ordered four 75-Watt equivalent LED light bulbs of 1100 lumens made by Feit Electric. Another question was who was going to be the investigator? All the students in the class wanted this job but considering the small population of our high school and the need for testing subjects we ruled this possibility out and we remained the sole investigator in this study. We started the study in the small HS library. We covered all the windows with black plastic not to be influenced by the sun light from outside. We tried to eliminate as much possible the variables that can affect the study. We discussed with our students all possible variables and errors we could think of. For a group of 11 students from High School we were expecting something an improvement in test results when we used LED light bulbs compared with CFL light. Even at a tie, a LED light bulb can provide more pleasant light (according to our senior students who choose the type of LED light) and it is energy efficient in the same time. That's what the LED lights were designed for.

The light bulbs used in this testing were the existing CFL light bulbs in the high school (a mixture of the two types recorded below) and the new purchased LED light bulbs:

a) CFL with brightness 1200 lumens, at 18 watts, light appearance 2700K, cool white and warm white;

b) CFL with brightness 900 lumens, at 13 watts, light appearance 2700K

and the new LED light bulbs cool white and warm white;

c) LED with brightness 1100 lumens at 14 watts, light appearance 3000K, soft white

Two types of tests were used to do this research.

1. Two SAT Reading practice test with 24 questions timed at 25 minutes were used for the junior and senior classes. The two tests were equivalent in difficulty and one was used to test the CFL lighting and the other one for the LED lighting. The results of the test were evaluated by checking the answer keys provided by the practice test.

15 students from the junior and senior classes (all our students present at school during the day the testing took place) took these tests. 4 students didn't get 60% (passing score) on one or the other test. They were dropped out from the study as being inconsistent.

2. Two tests of form drawing of 6 figures of similar difficulty timed at 15 minutes each were used for all the students in the high school who were present at school in the days the study took place. 35 students from grades 9 to 12 out of a high school population of 42 students were involved in the study. The quality of the drawing was evaluated by me. When in doubt , we asked the opinion of a fellow faculty member. All the drawings were evaluated blindly. The judge didn't know what type of light bulb the student was exposed to when he evaluated the drawings. The study took place in two rooms in the high school: the high school faculty library and the science lab. Students didn't know what type of light bulbs were used at the time of the testing since a translucent plastic cover that doesn't allow the shape of the light bulb to be distinguished covered the light bulbs. To minimize the variables, the testing took place at the same time of day (usually mornings during main lesson block) and on the same day of the week. There is a small difference between students' performance Monday compared with other days of the week.

Results and discussion

Results for the library room

The first room to be used was the high school library, about 60sqf surface that is illuminated by 4 light bulbs. During the study the windows were covered by black plastic to reduce the influence of the natural light, that can be anywhere from sunny to overcast sky.

Out of 15 students tested for reading, 4 students didn't get 60% (passing score) on one or the other test. They were dropped out from the study as being inconsistent.

Table 3. Influence of illuminating in classroom on success of students

Room	Number of students tested	Invalid subjects	Type of test	Higher score with LED lights (%)	Higher score with CFL lights (%)
Library	15	4	SAT reading	64%	36%
Library	21	1	Form drawing	60%	40%

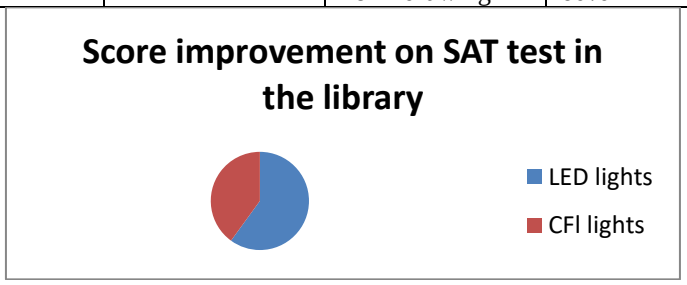

Fig 1. Score improvement on SAT test in the library

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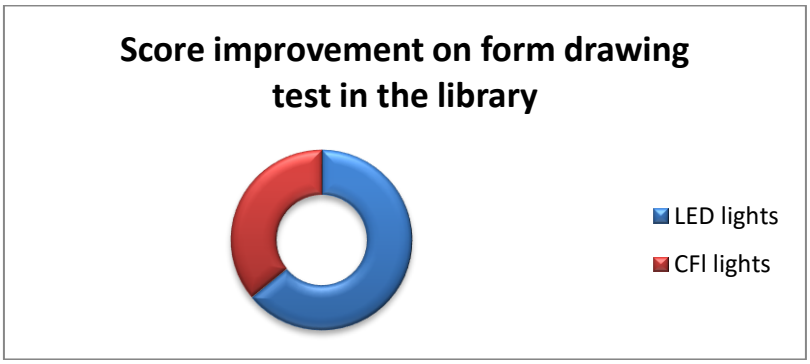

Fig 2. Score improvement on form drawing test in the library

The remaining students scored as following for the reading:
7 students (64%) scored one to six points (answers) better with LED light bulbs than CFL light bulbs
4 students (36%) scored one to four points (answers) better with CFL light bulbs than LED light bulbs.

21 students from grades 9 and 12 were tested with the form drawing test.
1 student was dropped from the study because didn't finish the drawing.
12 students (60%) out of 20 performed better with LED lights than CFL.

Fig 3. Photo above: Farber's Center Room#3 illuminated by light bulbs
Fig 4. Professor Dan Manzini, Switzerland, lecture in Farber's Center in Room#3 illuminated by light bulbs.

Results for the lab room
Testing in the lab room took place in normal conditions in a school day. The windows were not covered. The room has a surface of about 700sqf and 8 windows. It is illuminated by 30 light bulbs. Students didn't know what type the light bulbs were used at the time of the testing since the light bulbs are covered by a translucent plastic cover that didn't allow the shape of the light bulb to be distinguished.
Due to time pressure only the drawing form test was administered twice, one time with CFL lights and the other time with LED lights. The students were blind to the type of lighting used at the time of testing.

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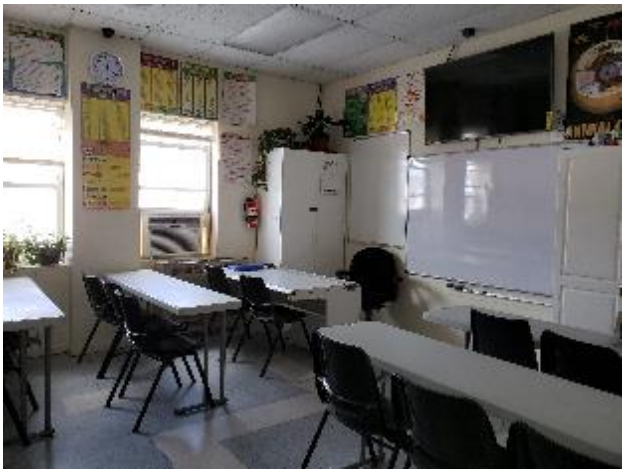

Fig 5-6. Photo above: Farber's Center Room#4 illuminated by natural light. The lights are turned off.

Table 5 Influence of illuminating in lab on success of students

Room	Number of students tested	Invalid subjects	Type of test	Higher score with LED lights (%)	Higher score with CFL lights (%)
Lab	28	2	Form drawing	54%	46%

28 students to from grades 9, 10 and 12 took part in this testing. The results were evaluated in the way described earlier.

2 students were dropped from the study because they didn't finish the drawing.

14 students out of 26 (54%) performed better with LED light than CFL.

Due to time and space restrictions the SAT reading test wasn't administered.

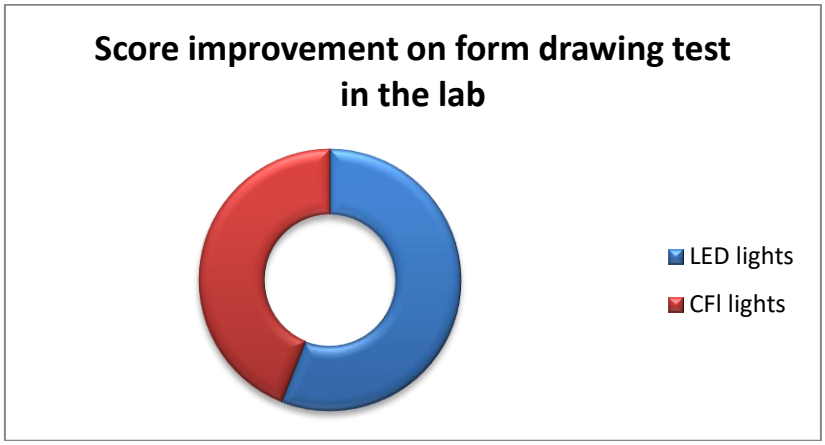

Fig 7. Score improvement on form drawing test in the lab

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Fig 8. Photo above: Farber's Center classroom illuminated by natural light. The lights are turned off Students enjoy environment and natural light.

Two weeks after the end of the study all the students in the high school got a chance to be exposed to the LED lights in the lab without knowing what type of light was a survey questionnaire was handed to all students in the high school except the seniors who had prior knowledge of some details of the study

Survey Questionnaire

1. Which type of light bulb is the most energy efficient?
a) Incandescent
b) Fluorescent
c) LED
d) Halogen
2. Which type of light bulbs do you prefer to have in your room:
a) Incandescent
b) Fluorescent
c) LED
d) Halogen
3. Do you have LED lights at home?
a) Yes
b) No
4. How many?
a) 0
b) 1-5
c) More than 5
5. Where?
a) Living room
b) Bedrooms
c) Hallways
d) Other places
6. Which room in the high school has the best lighting (light bulbs) for reading?
a) Emerson
b) Lab
c) Brown wing
d) Richard's room
7. Between the lab and Richard's room (room of equal surfaces and equal number of light bulbs) which of them has the most pleasant light bulbs lighting?
a) Lab
b) Richard's
8. Between the lab and Richard's room which room has the strongest light bulbs lighting for reading?
a) Lab
b) Richard's room

9. During the daytime does the lighting from the light bulbs in the high school help you to read better than just having the natural lights that comes through the window without any artificial lighting?

a) Yes
b) No

Interpretations of the survey questionnaire results

30 students from the grades 9, 10, 11 representing 96% of the students enrolled in these classes took the survey questionnaire. The students were totally blind. They didn't know where the LED or CFL light bulbs were installed in the school and they didn't know what the purpose of the study was.

1. Which type of light bulb is the most energy efficient?

17 students (57%) indicate LED as the most energy efficient light bulb

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10 students (33%) indicated CFL as the most energy efficient light bulb

3 students (10%) answered that they didn't know, even if this answer wasn't an option

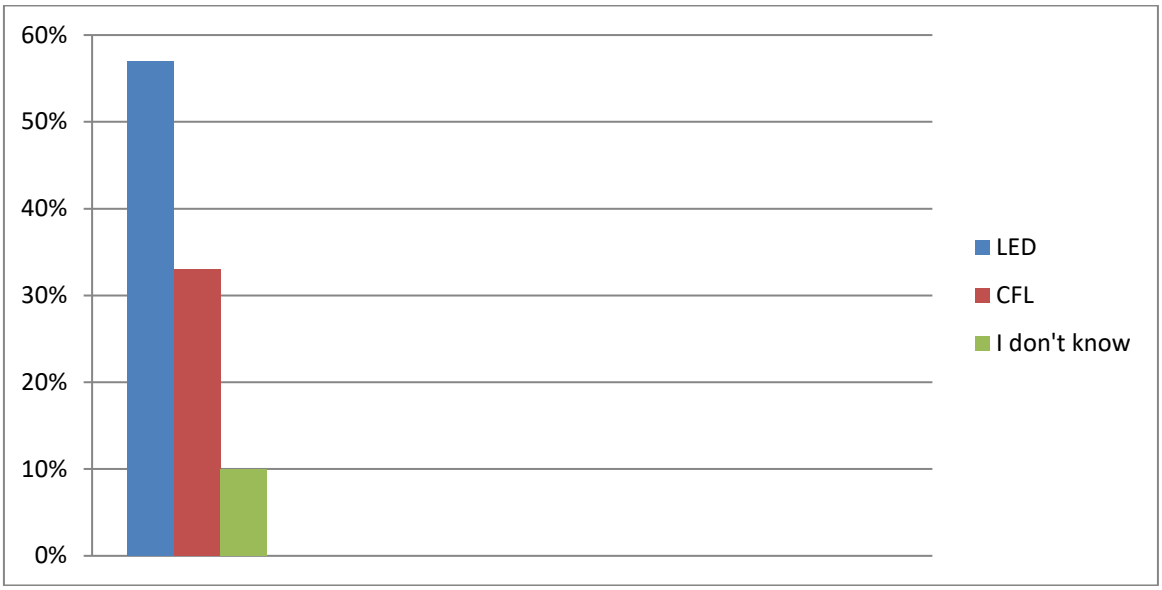

Fig 9. Results of testing after questionnaire. Which type of light bulb is the most energy efficient?

It is interesting to note that none of these students had an optics course in high which is taught in 12th grade, where the LED and CFL light bulbs are presented. 13 students who indicate LED as the most energy efficient light bulb actually have LED light bulbs at home (all the students who were aware that they have it).

2. Which type of light bulbs do you prefer to have in your room:
13 students (43%) prefer incandescent light bulbs
9 students (30%) prefer LED light bulbs
8 students (27%) prefer CFL light bulbs

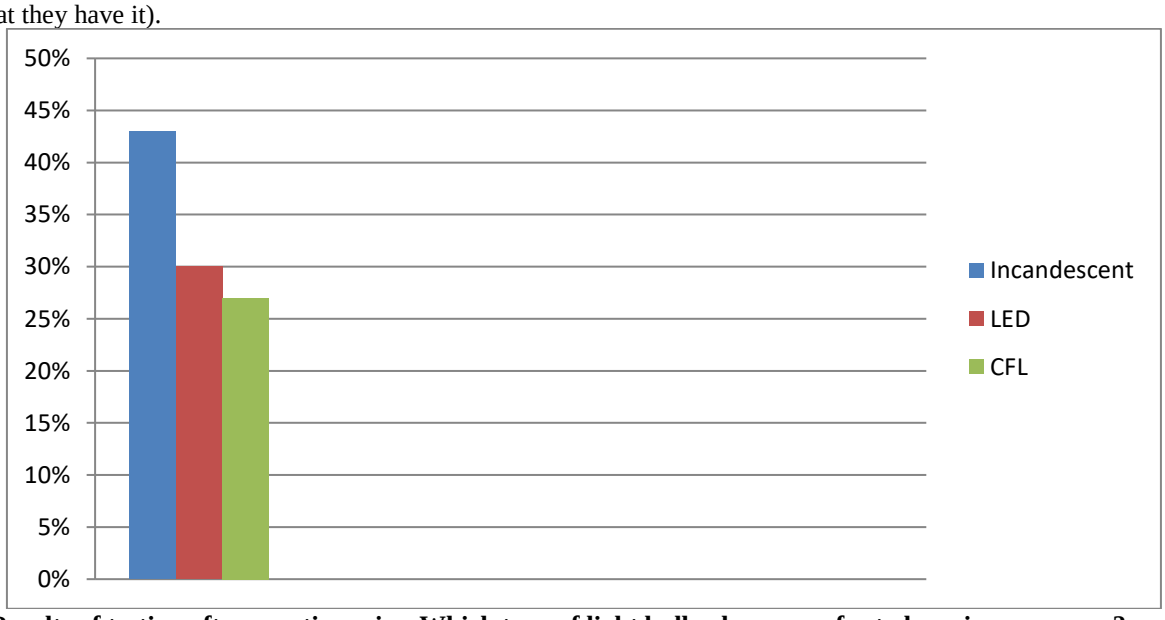

Fig 10. Results of testing after questionnaire. Which type of light bulbs do you prefer to have in your room?

This result is not surprising because the majority of students have incandescent light bulbs in their bedrooms. We found somehow surprising that 27% of students prefer CFL lighting. This indicates that the students are accustomed to CFL lighting. We have heard numerous complaints from adults about CFL lighting, but I haven't seen an actual survey.

3. Do you have LED lights at home?

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13 students (43%) answered yes
17 students (57%) answered no or they weren't sure

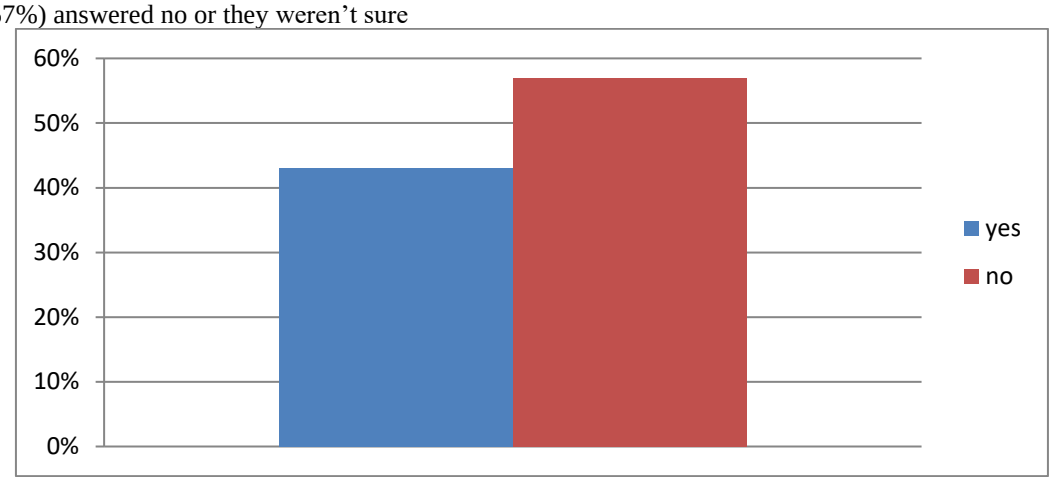

Fig 11. Results of testing after questionnaire. Which type of light bulbs do you prefer to have in your room

We found that the rate of LED light bulbs penetrations in school community households is rather low considering that average family income is above the state level and also the level of education of parents is above state average. Also, the incandescent light bulbs are not produced anymore since January 2014. It points out that CFL light bulbs are the norm in our school community families.

4. How many LED light bulbs do you have at home?

Just 3 students out of the 13 who have LED light bulbs at home have more than 5 LED light bulbs at home. The other students have less than 5 or are not aware about the number.

5. Where are the LED light bulbs located at home?

Only 5 students out of the 13 who have LED light bulbs at home have them in their own bedroom. The others have them on hallways or other places. But just 3 out of the 5 students actually prefer them in their bedrooms. It might also be an inconsistency in the answers.

6. Which room in the high school has the best lighting (light bulbs) for reading?
This question was confusing, since we were asking later which room had the most pleasant and strongest lighting and we decided to toss it out.

Between the lab and Richard's room (room of equal surfaces and equal number of light bulbs) which room has the most pleasant light bulbs lighting?

20 students (67%) choose Richard's room as the room with the most pleasant lighting. This room has 30 CFL light bulbs.
10 students (33%) choose the lab. The lab has 30 LED light bulbs.

It is also relevant to point out that Richard's room has 3 extra windows and the walls are painted in warm nice colors. Also, for the same type of question, the question number 2, a significant number of students answered that they found the CFL light bulbs pleasant or at least they were used to them. These answers suggest that many students are already accommodated with the fluorescent lights and any new type of lighting (LED for example) appears at least uncomfortable and unpleasant.

7. Between the lab and Richard's room which room has the strongest light bulbs lighting for reading?

21 students (70%) indicated the lighting in the lab as strongest where are the LED light bulbs compared with Richard's room where are the CFL light bulbs.
9 students (30%) indicated Richard's room as the room with the strongest lighting.
Actually, the LED light bulbs in the lab provide a higher brightness 1100 lumens compared with 900 lumens for the CFL light bulbs. LED light bulbs of 1100 lumens are more energy efficient than the CFL light bulbs of 900 lumens.

8. During the daytime does the lighting from the light bulbs in the high school help you to read better than just having the natural lights which comes through the window without any artificial lighting?

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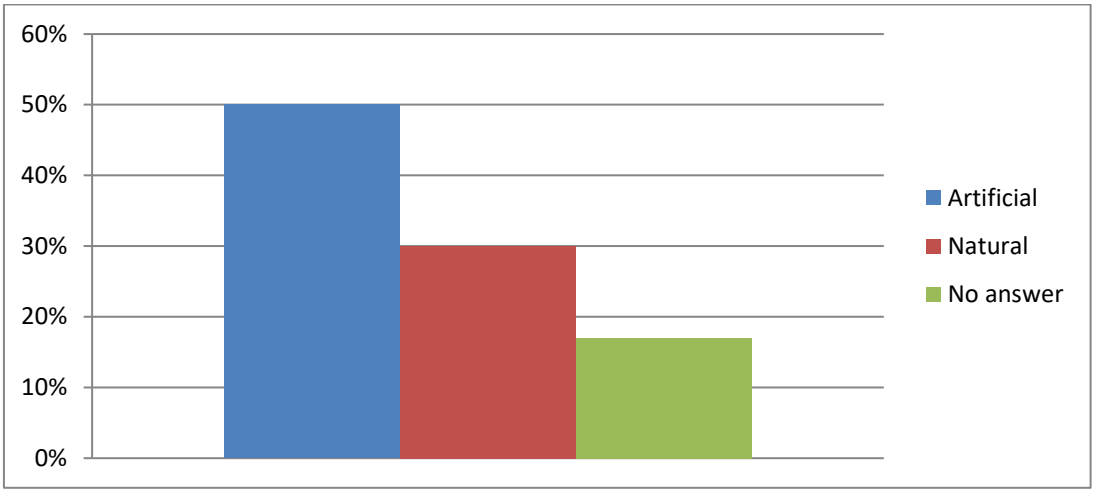

Fig 12. Results of testing after questionnaire. Between the lab and Richard's room which room has the strongest light bulbs lighting for reading?

Students (50%) still want the artificial light on during day time, and that is what happens right now in the school. During the school program from 8AM to 3:15 PM all the lights are on. 10 students (33%) prefer no lighting during daytime, being satisfied with the natural light that comes through the window. 5 students (17%) didn't answer the question. It is also relevant to mention here that we have lot of tall trees around the high school especially in the front of the science lab windows that provide shade. The shade is welcome in the hot and sunny days of the North Carolina hot season from April to September. The shade of the tree deduces the cost of air conditioning in the school, but has a negative impact on the incoming natural light in the building.

At the end of this study we came up with a few conclusions.

First conclusion is that a study of this type is time consuming and the logistic is overwhelming for a single researcher, especially when this researcher is a full-time busy science teacher. Having a bigger research team and more resources like more rooms and more light bulbs to use will give more precise and significant results. A second conclusion is that high school teenagers don't make the best study subjects. We had many students who came in the morning sleepy and moody at school and a few of them needed to be eliminated from the study due to inconsistencies in their attitude and behavior that affected the study results. We imagined that a military school with students of ages 19 to 25 would provide ideal subjects for such a study. A third conclusion is that many students and their families are not aware about LED lights. We think the biggest impact of this study was to create awareness in the Emerson Waldorf School community about the use of LED lights. Administration was very supportive and phases out the CFL lights as they got burned out and replaced them gradually with LEDs. And fourth we think that designing school building with more windows and skylight to allow more natural light in the building is the best answer for school lightning as it was pointed out by some of students in the survey questionnaire at the end. As seen in Table 1, a significant number of students had obtained higher scores on tests when CFL light was in use. These results can be explained by the fact that students were already accommodated with CFL lights since it was the only type of lighting, they had experienced during their school life time. To counter this tendency of accommodation with CFL lights, LED lights should be introduced in the room where the study takes place early enough that the students get used and feel comfortable with these types of light. How should we improve this study if we want to do it again at other school? Firstly, we should ask for help from adult teachers and staff in the school. Secondly, we will start with more light bulbs. Thirdly, we would use more refined methods of testing like **Brickenkamp's d2 test of attention**. The d2 test is standardized, it is more developed version of the cross-out test. It measures the speed and accuracy of a person's working behavior when differentiating between similar visual stimuli (detail discrimination), so it allows evaluation of their individual performance with regard to attention and concentration. And fourth we think that designing school building with more windows and skylight to allow more natural light in the building is the best answer for school lightning as it is pointed out by some of students in the survey questionnaire at the end.

The study at Waldorf School of Saratoga Springs, NY

In the fall of the year 2015 we conducted research at the Waldorf School of Saratoga Springs from upstate New York and continue research at Farber's Center for Academic Success.It was good opportunity to continue investigation about the influence of lighting on student learning. As the results from the study at Emerson Waldorf School were somewhat inconclusive, we intended to continue the study at

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this school. The new location presented some good opportunities for research study. The high school building was much bigger than Emerson Waldorf high school building. There were two levels building containing eight classrooms and numerous offices, hallways and storage rooms. There were no trees around the high school building, compared with EWS to provide shade. That means natural light had a bigger influence in illumination. The administration was very supportive of this study. LED lights were purchased the we replaced older light bulbs. Teachers should provide the time, the space and allow the students in their classes to be part of this study. There was a supportive mentality toward energy efficiency in the administration and in the school community. The high school has an agreement with the local electrical company to receive all the electrical power from renewable sources. All the people involved in this study had been volunteers. We had used in research only the classroom locations that the resident teachers were willing to volunteer for the study. It was pleased to find that all the 44 students in the high school from 9^{th} grade to 12^{th} had agreed to be volunteers in the study. The level of interest of the student about this study has been high. Since the students were our subjects in this study, we needed to keep them blind about the type of lighting we were using. We were planning to share with students the findings of this study next school year during Visual Physics block and in a high school Forum.

An intuitive approach to illumination in the building

Our first approach in researching the illumination in the high school was empirical and intuitive. Eventually we got more experiences with the illumination in each space of the high school building. We asked the senior students to take a survey about how they perceived the illumination of the building in different spaces. The students were given to read in different areas of the high school the following text printed in an Arial font size 8:

Experiment 1. Congress Park Pond

Read this carefully and ask questions if not clear. Leave these instructions in the classroom. Don't take anything with you. Maintain silence on the way there, while observing at the pond, on the way back, and after returning to the classroom. Walk to pond in silence, paying attention to what you see along the way in detail. Tune out sounds, smells, and touch as much as possible. This is practice for the pond observations to follow.

1. Pick out a spot along the bank of the pond, where the surface is fairly still, and at least 15 feet away from other people. Turn your body at right angles to the shore, looking along the bank and not at the water. Close your eyes, and remain until you can tune out sounds, smells, and touch as much as possible.
2. Rotate to face the pond, keeping eyes tightly closed. Flash both eyes open and shut, like a fast camera shutter. Note what you observe keeping eyes shut. Open your eyes, noting what happens then.
3. Observe the pond and surroundings ahead and to the sides in as much detail as possible. Maintain silence. Include the near bank, all the water from the near shore to the other banks, and the surrounding vegetation and trees up to and into the sky. Look for colors and shapes and how they vary. Include what you see on or beneath the pond surface, and its relationship to what is above. We will signal to return to the classroom after about ten minutes. Return to the classroom in silence. After arriving, silently write down your observations in words only. Then silently sketch the whole pond scene from memory. If we run out of time, finish it as homework to discuss tomorrow. We will signal when talking can resume.

The students had to answer Yes/No if they can read this text in a certain room, if the light in that room feel pleasant to them and to give a score on a scale 1 to 10 (1 worst lighting and 10 best lighting) according to their perception of the lighting in that room. The survey results for different rooms in the high school are recorded in Table 6

Table 6 The survey results for different rooms in the high school are recorded

Room	Is the lighting in this room pleasant for you? Yes/No	Can you read easily the text printed above in this room?	Give a score on a scale 1-10 (1 being worst lighting and 10 being the best lighting) according to your perception of lighting in this room.
Biology room	57% yes	100% yes	6.71 average
Math room	57% yes	100% yes	6.28 average
Practical Arts room	86% yes	100% yes	7.92 average
Faculty kitchen	64% yes	100 yes	7.07 average
Office #3	71% yes	93%yes	6.29 average
Main HS office	93% yes	100.00%	6.5 average

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Eurythmy room	93% yes	100.00%	7.85 average
Lecture Hall	86% yes	100% yes	7.5 average
Physical science room	79% yes	100% yes	8.25 average
Purple room	79% yes	100% yes	7.5 average
Art room	93% yes	100% yes	7.78 average
First floor hallway	64% yes	100% yes	6.78 average
Second floor hallway	57% yes	100% yes	6.0 average
Storage room	57% yes	79% yes	5.28 average

A total of 14 senior students took part in this survey. The way the questions had been asked suggested that the score on the scale 1 to 10 for each room depended on two criteria:
1) The students can read the text printed in the Arial size 8 font in that space and
2) Do the lighting in the room appear pleasant to the student
According to their answers the students were able to read the text in all the rooms with the exception of 3 students who couldn't read the text in the storage room. This was not surprising, since the storage room had very poor artificial lighting and the windows are covered with shelves full of books. Also, one student reported that couldn't read the text in an office. The rooms with the most unpleasant lighting were not a surprise. As we mentioned before, the storage room not only had very poor light, but was also a cluttered and dusty space, a very unpleasant place to be. The second-floor hallway has also poor lighting and doesn't have any windows or skylights. The Math room and the Biology room were the classroom spaces with the most negatives. Both rooms had plenty of light bulbs relative to their area and plenty of windows for natural light and receive sunlight in the morning. We asked directly the students why the lighting in these rooms appears unpleasant and we received an interesting answer from students. The light bulbs were a mixture of incandescent and fluorescent light bulbs and this made the light appear not uniform in these rooms and apparently disturbing to the students. It seems that initially all the light bulbs in the high school building were incandescent and they were replaced with fluorescent light bulbs when they malfunctioned. The spaces with the most pleasant lighting were the Art room, the Eurythmy room and the Main HS office. The Art room and the Main HS office had a big window surface relative to the area of these rooms and it meant they had received plenty of sunlight. The Eurythmy room did not get so much natural light, but was the only room in the high school with dimmable light. Also, all these three rooms had the walls painted in light and warm colors as opposed with other spaces in the school. The color of the walls plays an important role in the way the light is received by the students. It was obvious in the Physical Science room where a project to paint the room took place. When the dark blue walls of this room were painted white to cover the previous color, the whole lighting in the room changed fundamentally. At the time of the survey the Physical Science room was the only classroom in the high school illuminated by LED lights. The other space in the high school illuminated by LED lights was office #3. The math and biology room had a mixture of fluorescent and incandescent light bulbs. The practical Art room had only fluorescent light bulbs. The Eurythmy room had also a mixture of incandescent and fluorescent light bulbs, but they were distributed uniform in the two parts of the room. The physical science room received the highest score in the high school. This is not surprising because the lighting in this room is superior quantitatively compared with other spaces, by number of light bulbs in the room (25), the high luminosity of the light bulbs (1100 lumens LED light bulbs) and the number of windows (7). The lowest score was obtained without surprise by the storage room that had just one weak incandescent light bulb functioning and practically no natural light. The Practical Arts room the Eurythmy room and the Art room were also spaces with high scores. An important aspect of these spaces is that the main pedagogical activity taking place is artistic in nature and very little academic (reading texts). Most of the senior students have spent four years in the high school, they know all the spaces very well and they are well accommodated to them. At the time when this survey took place all the rooms had incandescent and fluorescent lighting, except the Physical science room where the LED lights were installed 6 months before. The purpose of doing that was to give students enough time to accommodate to the new type of lighting. The results of the study at Emerson Waldorf school has shown that students could accommodate to the type of lighting that had for long time in use in their classroom. Since all our senior students had learned in the Visual Physics block about different types of learning we gave them one more survey questionnaire to find out how they use and perceive the four types of lighting: incandescent, fluorescent, LED and natural light.

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Survey Questionnaire

1. What type of lighting do you have at home? Circle all types of lighting that apply.
A) Incandescent
B) Fluorescent
C) LED
D) Others _____
2. Circle the type of lighting that is in use at home in the room you do the most of your reading (homework) at home.
A) Incandescent
B) Fluorescent
C) LED
D) Others_____
3. What type of lighting do you prefer to have at home in your room?
A) Incandescent
B) Fluorescent
C) LED
D) Others_____
4. What type of lighting is most energy efficient?
A) Incandescent
B) Fluorescent
C)LED
D) Others_____
5. What room in the high school has the best lighting (natural and artificial) for reading?
Name the room: _____
6. During the school day does the light bulbs in the high school classrooms help you to read better than just having the natural light that comes through the windows without any artificial light?
A) Yes
B) No

Answers question 1
11 students (79%) have at home incandescent lighting, 6 students (43%) have fluorescent lighting, and 5 students (36%) have LED lighting. 6 students (43%) have incandescent lighting the only type the lighting at home and one student has
at home only LED lighting. 2 students (17%) have all three types of lighting at home.

Answers question 2
11students (79%) use predominantly incandescent lighting at home, 2 students (17%) use fluorescent lighting, and one student uses LED. Probable is the student who has only LED lighting at home.

Answers question 3
8 students (57%) prefer incandescent lighting at home, 5 students (36%) prefer LED lighting at home and only one student prefers fluorescent lighting.
Interesting to observe that even if 6 students have fluorescent lighting at home just one prefers to use it.
Incandescent lighting and LED are the most popular. The preference for the LED lighting is limited to the number of students who have this type of lighting at home.

Answers question 4
An overwhelming number of 13 students (93%) think that LED lighting is the most energy efficient. One student has answered that the sunlight is the most energy efficient type of lighting!

Answers question 5
10 students (72%) think that Physical Science room has the best lighting for reading. One student has made a comment that this is due to the natural light. Three students have chosen the Purple room and one student has chosen the Lecture Hall. The Physical Science room and the Purple room are bot on the second floor, have plenty of windows (the most in the school) and are oriented toward South getting the most exposure to sunlight during the school program.

Answers question 6
9 students (64%) don't find any help in having artificial lighting to read better, 4 students (29%) find artificial lighting useful for reading, and one student has a more nuanced answer: artificial lighting is useful for reading in the winter and darker months, but not when the sun shines.
To summarize the answers of the students from this survey, students prefer natural light. Artificial lighting can be useful in darker days, but only a minority of students prefers it.
Incandescent lighting is the lighting of choice for most student, but it is also more widely in use in the home of the most students. When available LED lighting is preferred. Florescent lighting is not preferred even if it's available to a number of students at home.

How much lighting is needed in the classroom?
The layout of the high school

The first question that we posed during this second stage of our study was if the illumination in the building was sufficient to conduct intensive reading and writing.

The high school building contains eight classrooms with windows, two interior hallways without windows, five offices with windows, a photo lab room without windows, a storage area with windows, two storage area without windows, four restroom areas with windows and a basement without any natural light.

Our focus was on the classrooms where all the learning took place. The office rooms are used only by faculty and administration. Three of the classrooms (Purple room, Physical Science room and Biology room) have many

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windows facing South East and that means they get lot of natural light during the school program (8:20 AM to 2:40 PM). Two rooms (Practical Arts room and Math room) are facing east. They get lot of natural light during the early hours of the day, but they can be darker in the afternoon since the sun is positioned southern in the early afternoon. The Art room is located on the second floor is facing north, but has a good natural illumination due to the big surface of windows relative to the small space of the room. The Lecture Hall room is also facing north and has the same number and surface of windows as the Art room, but has double the room space. It appears quite dark inside especially during cloudy days. Eurythmy room is the space with the biggest surface of the room. It has four windows facing south and four windows facing north. We observed that the teacher kept the southern windows covered with shutters, possible to prevent a strong sunlight interfere with the pedagogical activity in that room. We have observed during faculty meeting that took place in the Eurythmy room late afternoons that the illumination in the room was sufficient for a movement activity as Eurythmy, but was not enough for reading a text with small print. Some teachers who participated in experiment were in late forties, but they could read without glasses if the illumination in the room is sufficient. However, in the Eurythmy room, they needed glasses to read and I observed that almost all our faculty colleagues were in the same situation. During the school program all the lights in all the room are on. The intention is to assure a maximum level of illumination for students and faculty. We have noticed that is a big difference in illumination between a cloudy day and a dark winter day compared with a sunny spring day, regardless if the lights were on. That means that during the days when the natural light is not adequate the artificial light makes the difference. Lighting design for classroom and educational facilities must take into consideration the quantity and quality of light while keeping the cost at reasonable level. Fluorescent fixtures are traditionally and still currently the most popular fixture in classroom design because it is able to fulfill the recommendations for quality and efficiency, while still maintaining a reasonable budget. Lighting systems are designed based on the light levels or illuminance required by the tasks performed within each space. The accepted authority for appropriate illuminance values is the Illuminating Engineering Society of North America (IESNA). The IESNA publishes a comprehensive Handbook along with supplemental Recommended Practice Guides that provide tables of appropriate illuminance data.

The light levels recommended by the Illuminating Engineering Society of North America (IESNA) are an average of 50-foot candles (fc) for reading and writing tasks.

Lighting Calculation Terms

One candela is equivalent to the illumination from one standard candle.

One-foot candle is the amount of illumination on a surface created by a light source of one candela that is a foot away from the surface. For those using feet, one-foot candle is equal to 1 lumen/square foot. For those using meters, one lux is equal to 1 lumen/square meter. When we purchase light bulbs there will generally be two numbers of interest on the packaging. One is Watts, which measures the power draw of the bulb. The other is lumens. A lumen is a measurement of light directly relevant to human beings. Instead of trying to measure the number of photons or raw radiated energy, the lumen scale describes the amount of light, or brightness, that the human eye perceives. All modern light bulb packaging shows the number of lumens the bulb produces. A watt is a measurement of electrical power, formally equal to the amount of energy in 1 ampere of current flowing at 1 volt. The relative efficiency of different light bulbs can be assessed by comparing how many lumens they produce for every watt of electrical power.

How to Calculate Brightness for a classroom

a) Physical Science room

The Physical Science room has 25 fixtures that can accommodate different types of light bulbs located in the room as seen in the picture and drawing below.

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Fig 13. The lighting (LED bulbs) in the Physical Science room in early afternoon in summer.

The walls are painted white. The red dots represent the positions of the light fixtures and the blue lines the positions of the windows

Let's start by calculating the area of the of the Physical Science room. By multiplying the length and width of the room 41 feet x 22 feet we get 902 square feet. To calculate the required lumens for the room we multiply the number of foot candles recommended by the square footage. 50-foot candles x 902 square feet = 45100 lumens. An average 100-watt incandescent bulb, for example, produces about 1,600 lumens. 25 incandescent watt bulbs of 100-watt will produce 25x1600 = 40 000 lumens. This is less than the level of light recommended by IESNA. But the illumination in the room was even worse than that. To save electrical power all the light bulbs installed in the building were of 60 Watts. A clear 60 incandescent light bulb the type used in the high school building had about 550 lumens. 25 light bulbs x 550 lumens = 13 750 lumens

This is less than a third of the lighting required! They are also on the market 60W incandescent light bulbs that give more lumens, but they are more expensive. Anyway, nobody has calculated the level of the illumination in the room or at least had the expertise to do so. How is still possible for the students to function in this room? The answer is simple: the 7 windows (drawn in the picture above) with a surface of 18sqf each provide additional natural light necessary for reading and writing.

The natural light alone, or the 25 light bulbs by themselves are not sufficient to provide a decent level of illumination the classroom. Together they are barely sufficient. We had one night a parent conference in the classroom when outside was dark and we noticed that the lighting was insufficient for reading. Also, in a cloudy, dark winter day the lighting appears to be insufficient. It seems that the main concern for using 60 W instead of 100W was the cost of electrical power. We have replaced all the 25 light bulbs in the room with soft white LED light bulbs produced by Cree that use only 9.5 W and have a brightness of 800 lumens per bulb. They produce 25 x 800 lumens = 20,000 lumens This is 6250 lumens increase (45%) in brightness and a six-fold decrease in energy consumption! The only drawback of doing changing the light bulbs was the price of the LED light bulbs ($10) but this is recovered in 2-3 years of continuous use.

b) Biology room

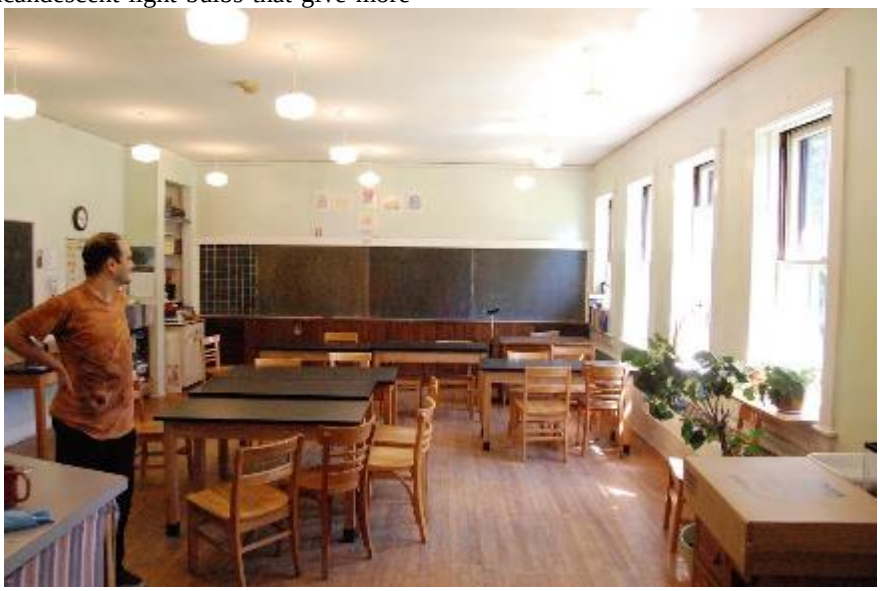

Fig 14. The lighting (LED bulbs) in the Biology room early afternoon in spring

The Biology room has a total area of 655 square feet.
The required lumens for the room are
50-foot candles x 655sqf = 32750 lumens
There are only 13 light fixtures in this room that can accommodate as many light bulbs.

It is obviously that the 60Watts incandescent light bulbs of 550 lumens each can't even provide a quarter of the lighting needed.

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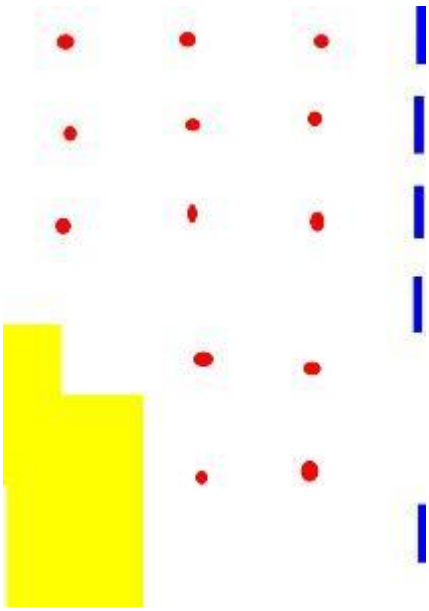

Fig 15. The red dots represent the position of the light fixtures and the blue lines the positions of the windows. The yellow area is not part of the room.

In this room we found 6 incandescent light bulbs of 60W and 7 compact fluorescent light bulbs (CFL) of 13 W and 900 lumens. It is clear that the compact fluorescent light bulbs provide more lumens by using significantly less power, however they appear annoying to students during our intuitive survey. The actual number of lumens in the room was 6 x 550 + 7 x 900 = 9600 lumens we replaced the light bulbs in this room with LED light soft white produced by Cree of 13.5 watts and 1100 lumens. 13 light bulbs x 1100 lumens = 14300 lumens There was 4700 lumens increase (49%) in luminosity while saving a significant amount of electrical power. It was worth to notice that the CFL light bulbs used in this room can save the same amount of electrical power, but they produce 200 lumens less per light bulb. In this room as in the physical science room the difference of needed lumens come from natural light through the 5 windows each with a surface of about 16sqf

Practical Arts room

Fig 16. The lighting (LED bulbs) in the Practical Arts room early afternoon in spring

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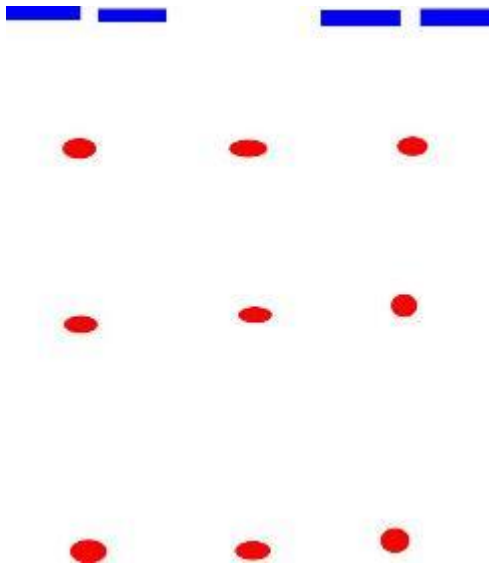

Fig 17. The red dots represent the positions of the light fixtures and the blue lines the positions of the windows

The practical arts room has an area of 24 feet x 21 feet = 504sqf the required lumens for the room are 50-foot candles x 504 lumens = 25,200 lumens There were only 9 light fixtures in this room that can accommodate as many light bulbs. The room had 9 compact fluorescent light bulbs of 13 W and 900 lumens. 9 X 900 lumens = 8100 lumens we replaced the light bulbs in this room with LED light soft white produced by Cree of 13.5 watts and 1100 lumens. 9 x 1100 lumens = 9900 lumens. It is 1800 lumens increase (22%) while using almost same electrical power.

The science lab at Emerson Waldorf School

The science lab at Emerson Waldorf high school has an area of 700sqf and 30 light fixtures. The required lumens for the room are 50-foot candles x 700 = 35, 000 lumens. The CFL light bulbs used in the room had a brightness of 1200 lumens and the LED light bulbs used for that study had 1100. If we multiply these values with the number of the light bulbs, we will observe that there is a sufficient amount of lighting in the room even in evenings or a cloudy day. To reduce the brightness during the daytime when the sun shines, the architect has designed the lighting so that there two switches that control half of the light bulbs each. The answer against glaring is to turn off half of the light bulbs. The lighting level in all the three-room investigated was significantly insufficient to have evening classes in the building. During the day time the difference in lighting required for reading or other activities that require attention is compensated by the natural light that comes in the rooms through the windows. Even with the natural light, the lighting is insufficient in a cloudy day. The LED light bulbs brought a 22% to 49% increase in the lighting level in the room depending of the number of the light bulbs in the room and type of the older light bulbs replaced. Right now, the lighting level in the daytime seems to be just right. Evening classes will require light bulbs of 1600 lumens or stronger, but in this case the lighting will be too strong in the daytime. The solution is to use dimmable lighting with the light bulbs with the strongest brightness on the market. As the eye ages, it requires lighter to see the same detail with the same speed and accuracy. For this reason, lighting systems must be designed with specific human needs in mind. A classroom designed for children might require only 40-foot candles, while the same classroom designed for adult activities might require 80-foot candles or more. Today, lighting levels at home, school or office may range from 20 to 100-foot candles or more. It is very clear that the LED light bulbs feature a higher ratio of lumens to watts than incandescent bulbs. Also, the LED light bulbs used have the advantage that is omnidirectional; they shine uniformly in all directions.

A qualitative assessment of the illumination in the building using the Brickenkamp d2 attention

One issue with the tests administered at Emerson Waldorf School has been the reliability of the test in the context of the uneven performance and the mood swings of the students. The Brickenkamp d2 test of attention has been the focus of intensive investigation regarding its reliability. Studies pertinent to the test's reliability indicate high internal consistency and high levels of temporal stability. The Brikekamp d2 test has being continuously developed and refined to reduce all the variables as much possible. In summary the d2 test is a user-friendly, reliable and a valid measurement of selective attention.

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Brickenkamp's d2 test of attention was originally developed in 1962 in Germany and Switzerland as an assessment tool for driving testing. Subjects who failed this test had difficulty to concentrate visual and to ward off distractions. The test consists of rows and columns of the letters *d* and *p*. This letter is accompanied by one to four dashes, arranged either individually or in pairs above and below the letter. The objective of the subject is to cross out each d with 2 dashes.

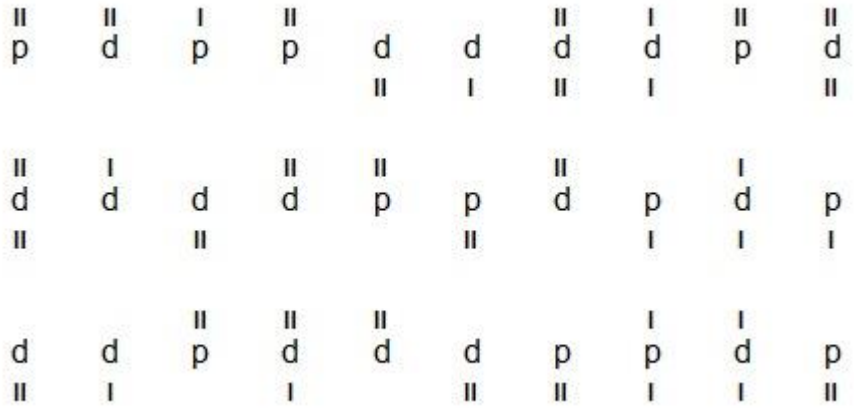

Fig 18. The Brickenkamp d2 test of attention

These are called the "relevant items". All other combinations of letter and lines are considered "irrelevant". The subject is allowed 20 seconds per raw. A raw has 21 or 22 relevant characters with a total of 299 relevant characters for a total of 14 rows.

Scoring

Two scoring keys were provided to assist the examiner in counting the number of characters marked and error rates. The first scoring key determines the TN and E1 and the second scoring key determines E2

$TN = \Sigma N$

TN stands for the " Total Number of Items Processed". TN is a quantitative measure of performance of all items that are processed, both relevant and irrelevant ones. TN is a highly reliable and normally distributed measure of attention allocation (selective and sustained), processing speed, amount of work completed, and motivation.

$E= \Sigma (E1 + E2)$

The raw score E (Errors) is the sum of all mistakes. This includes errors of omission (E1) and the less common errors of commission (E2).

Errors of omission occur when relevant items ("d" with two dashes) are not crossed out.

Errors of commission occur when irrelevant letters are crossed out in violation of the instruction.

$E\% = 100\ \Sigma (E1+E2) / \Sigma N$

E% (Percentage of Errors) represents the proportions of errors made within the area of all items processed. The smaller is the proportion of errors, the better is the subject's accuracy, quality of work, and degree of carefulness.

Physical science room

10 students from 9th grade took the Brickenkamp d2 test in the Physical Science room in May 2015.

First time the test was administered it with LED lights. The LED light bulbs have been in place for 6 months and students had regular classes in this room. The lights bulbs were covered with semi opaque glass. The students couldn't distinguish what type of light bulbs was used, that means they were blind subjects in this study.

Table 7 Attention test results for LED lights in Physical science room

Subject	Σ N (Total number of items processed)	E1+E2 (Total number of errors)	E% (Percentage of Errors)
Student 1	194	88	45%
Student 2	245	57	23%
Student 3	255	53	21%
Student 4	213	88	41%
Student 5	199	100	50%

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Student 6	285	14	5%
Student 7	198	85	43%
Student 8	240	61	25%
Student 9	252	51	20%
Student 10	258	44	17%

The results of the attention test are recorded in the table 7. The average percentage of errors for the 10 students was **29%.** The test was repeated one week later with incandescent light bulbs with the same students at the same hour of the day. The natural lighting conditions were similar with the first date of the test. The results of the test are recorded in Table 8.

Table 8 Attention test results for incandescent lights in Physical Science room

Subject	Σ N (Total number of items processed)	E1+E2 (Total number of errors)	E% (Percentage of Errors)
Student 1	251	48	19%
Student 2	296	3	1%
Student 3	297	3	1%
Student 4	246	60	24%
Student 5	296	3	1%
Student 6	296	4	1%
Student 7	274	25	9%
Student 8	245	55	22%
Student 9	283	16	6%
Student 10	258	41	16%

The average percentage of errors for the 10 students was **10%.**

There is 19% percent difference between the two tests that is way out of margin of error.

Practical Arts room

The same Brickenkamp d2 attention test was administered to the same group of students in the Practical Arts room when the fluorescent lights were in use. The students were blind to the type of lighting they were tested.

Table 9 Attention test results for fluorescent lights in the Practical Arts room

Subject	Σ N (Total number of items processed)	E1+E2 (Total number of errors)	E% (Percentage of Errors)
Student 1	132	177	134%
Student 2	185	113	61%
Student 3	180	118	65%
Student 4	199	98	49%
Student 5	161	138	86%
Student 6	139	167	120%
Student 7	189	115	61%
Student 8	126	176	137%
Student 9	184	114	62%
Student 10	193	106	55%

When the percentage of error is above 100% that means that the number of omission and commission error is bigger than the number processed. From the Table 9 results that average percentage of errors for the 10 students was **83%.**

Table 10 attention test results for LED lights in the Practical Arts room

Subject	Σ N (Total number of items processed)	E1+E2 (Total number of errors)	E% (Percentage of Errors)

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Student 1	204	105	52%
Student 2	282	20	7%
Student 3	287	33	11%
Student 4	192	108	56%
Student 5	287	14	5%
Student 6	197	105	53%
Student 7	228	74	32%
Student 8	229	72	31%
Student 9	270	31	11%
Student 10	188	111	59%

The test was repeated one week later with LED light bulbs with the same students at the same hour of the day. The natural lighting conditions were similar with the first date of the test. The results of the test are recorded in Table 10.

From the Table 10 results that average percentage of errors for the 10 students when the LED lights were in use was **31.7%**

Table 11 Comparison between attention test average percentage errors when different type of lighting was use in Physical Science and Practical Arts rooms

Room	Date of attention test	Type of lighting	Average percentage of errors
Practical Arts	May 12th, 2015 10AM	Fluorescent	83%
Physical Science	May 13th. 2015 2PM	LED	29%
Practical Arts	May 19th, 2015 10AM	LED	31.7%
Physical Science	May 20Th, 2015 2PM	Incandescent	10%

Table 11 compares the average percentage errors of the attention test for the same group of 10 students in the Practical Arts and Physical Science rooms when different types of lighting were used. The natural light intensity was about the same in the two rooms. Practical Arts room oriented east gets more sunlight in the morning and Physical Science room oriented south receives more sunlight early afternoon. However, the Physical Science room has more windows (7 windows with a surface of 126sqf) It is interesting to notice that in both rooms the average percentage errors of the attention test for LED lighting is very close, around 30%. The difference between LED lighting and fluorescent lighting in the Practical Arts room is 51.3% and that's a huge difference. It might be suspected that the attention test results in the presence of fluorescent lighting in the Practical Arts are worse just because it was the first time when the test was administered. That's not the case. The students practiced a sample test for training and warming at beginning of the test and the instructions were very clear and simple. Also, the percentages of errors for the attention test are distributed almost evenly across the group even when we have a few top performers and a few performers with lesser results. The results of the tests show that incandescent lights are the most comfortable for students to pay attention. However, they have more a qualitative effect on students' attention than quantitative. The test was administered in day with ideal natural light. In a cloudy day, or a dark winter school day the luminance from the incandescence light bulbs might not be enough as proven in the section 7.3.3 How to calculate brightness for a classroom.

Biology room

8 students from 11th grade took the Brickenkamp d2 test in the Biology room in May 2015. The lights bulbs were covered with semi opaque glass. The students couldn't distinguish what type of light bulbs was used, that means they were blind subjects in this study. At the time of the test, Biology room was illuminated by a mix of fluorescent and incandescent light bulbs.

The results of test are recorded in Table 12.

Table 12 Attention test results for fluorescent incandescent mix lights in the Biology room

Subject	Σ N (Total number of items processed)	E1+E2 (Total number of errors)	E% (Percentage of Errors)
Student 1	242	57	24**%**
Student 2	169	130	77%

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Student 3	158	141	89%
Student 4	155	144	93%
Student 5	195	105	54%
Student 6	154	145	94%
Student 7	175	124	71%
Student 8	136	166	122%

Table 12 results shows that average percentage of errors for the 8 students was **78%.**

The test was repeated two weeks later with LED light bulbs with the same students at the same hour of the day. The natural lighting conditions were similar with the first date of the test. The results of the test are recorded in Table 13.

Table 13 Attention test results for LED lights in the Biology room

Subject	**Σ N (Total number of items processed)**	**E1+E2 (Total number of errors)**	**E% (Percentage of Errors)**
Student 1	**193**	**106**	**55%**
Student 2	**151**	**145**	**91%**
Student 3	**277**	**22**	**8%**
Student 4	**181**	**118**	**65%**
Student 5	**205**	**95**	**46%**
Student 6	**279**	**20**	**7%**
Student 7	**208**	**91**	**44%**
Student 8	**177**	**122**	**70%**

Table 13 results shows that average percentage of errors for the 8 students when the test was taken with LED lights decreased to 4**8%.** There was a significant 30% difference in percentage of errors between the room being illuminated by LED and the room illuminated by a mix of fluorescent and incandescent light. Also, during our previous survey, the senior students have pointed out that the mixing of lighting from different light bulbs in a room is disturbing. In a test like Brickenkamp d2 attention test where you have to see the two small dashes around the relevant letter "d" under time pressure, the disturbance from light is translated in a higher percentage of errors for students taking the test. For this reason, Brickenkamp d2 attention test is a great tool to asses student attention and reading performance in different types of lighting situations.

Conclusions

It is clear that good lighting depends on more than just artificial luminance levels. Our study, conducted at Farber's Center for Academic Success, Inc and Saratoga Waldorf School, shows how much the general luminance in the high school building depends on natural light. Luckily the building has plenty of windows in each room and receives plenty of natural light. The reliance of a day school like Farber's Center for Academic Success, Inc., and Saratoga Waldorf School on natural light offer reasons to research the design possibilities for an optimum use of daylight. However, a classroom is a difficult space to light with daylight, because of the depth of the classroom and the different tasks, which must be performed in it. By combining a good daylight design with a good electric lighting concept, students can enjoy better lighting and the energy for electric lighting can be reduced substantially.

Incandescent lights appear to be the lighting of choice for the majority of students. Incandescent light bulbs of 100Watts providing 1600 lumens can be the ideal lighting device in school. This light is closest to natural light and is the most preferred by the majority of people. However, due to energy consumption reasons, incandescent light bulbs of 60W are used in general, but they don't provide enough luminance especially in the evening.

LEDs provide much higher light output on the same input power as comparable incandescent or fluorescent sources, because of their high efficiencies. This is also because the light emitted from the LED is naturally directional, and in almost all applications less light is lost in the fixture compared to traditional light sources.

LEDs light represent a good compromise between quality of light and energy efficiency. Also, the price of LED lights is decreasing steadily while quality is increasing, including the possibility of controlling each LED light bulb by remote control allowing the lighting to be dimmable.

The fluorescent lights appear to be the worst choice for the school buildings despite the fact that majority of schools in USA use them to save l energy. People avoid the fluorescent lights when they have a choice. Not only is the quality of fluorescent light uncomfortable to people's vision, the mercury contained in the fluorescent lamps is toxic for environment. Now that the price of LED is decreasing

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steadily and you can find affordable LED light bulbs on the market even the claim of energy efficiency is gone for the fluorescent lights.

This study has taken place in two schools over the period of four years. It has involved hundreds of hours of work, planning, writing, changing light bulbs in the classrooms, ordering supplies, taking surveys, administering tests, interpreting data.

We would like to thank administrations, teachers, and students for participating and helping in conducting research. The Farber's Center and Waldorf schools give lot of attention to the healthy physical environment for the students. Lighting provided by LEDs light bulb can bring an improvement in the health and learning performances of the students and at the same time making the buildings more energy efficient and bringing cost savings.
The intention of this study is to be shared with administrators of the schools and to create awareness about the improvements and opportunities the LEDs lights bring to any school building.

METHOD OF IMAGES AND INFLUENCE OF LIGHTING RADIATION INTENSITY ON STUDENT LEARNING EFFECTIVITY IN HYGIENE AND ERGONOMICS OF EDUCATION

Dr. Farber B., Professor Manzini D.

42 years ago, studying digital-light-color analogies in combination of mechanoreceptors, we created Method of teaching any subject, based on Images and Patterns. In this article we conducted research related to influence of lighting radiation intensity on student learning effectivity. Good ergonomic lighting depends on more than just artificial luminance levels. Our study, conducted at Farber's Center for Academic Success, Inc and Saratoga Waldorf School shows how much the general luminance in school buildings depend on natural light. Luckily the buildings have plenty of windows in each room and receive plenty of natural light. The reliance of a day school like Farber's Center for Academic Success and Saratoga Waldorf School on natural light offer reasons to research the design possibilities for an optimum use of daylight. However, a classroom is a difficult space to light with daylight, because of the depth of the classroom and the different tasks, which must be performed in it. By combining a good daylight design with a good electric lighting concept student can enjoy better lighting and the energy for electric lighting can be reduced substantially. Incandescent lights appear to be the lighting of choice for the majority of students. Incandescent light bulbs of 100Watts providing 1600 lumens can be the ideal lighting device in school. The light is closest to natural light and is the most preferred by the majority of people. However due to energy consumption reasons, incandescent light bulbs of 60W are used in general, but they don't provide enough luminance especially in the evening. LEDs provide much higher light output on the same input power as comparable incandescent or fluorescent sources, because of their high efficiencies. This is also because the light emitted from the LED is naturally directional, and in almost all applications less light is lost in the fixture compared to traditional light sources. LEDs light represent a good compromise between quality of light and energy efficiency. Also, the price of LED lights is decreasing steadily while quality is increasing, including the possibility of controlling each LED light bulb by remote control allowing the lighting to be dimmable. The fluorescent lights appear to be the worst choice for the school buildings despite the fact that majority of schools in USA use them to save electrical energy. Now that the price of LED is decreasing steadily and you can find affordable LED light bulbs on the market even the claim of energy efficiency is gone for the fluorescent lights. This study has taken place in three schools over the period of 5 years. It has involved hundreds of hours of work, planning, writing, changing light bulbs in the classrooms, ordering supplies, taking surveys, administering tests, interpreting data.
Keywords: lighting radiation, school, hygiene, education

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