ZUMTOBEL

Dynamic Lighting in Classrooms: A new interactive tool for teaching

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Abstract

This paper presents the results of a field study about the use of lighting as a tool to structure and support teaching and learning activities. Dynamic lighting technology with the option to choose from four different lighting scenarios was installed in classrooms in a Danish elementary school. The way the teachers worked with the lighting was analysed using qualitative research material from observations and interviews and quantitative data from the lighting control system, which recorded the specific lighting scenarios chosen by the teaching staff. This study revealed various different motivations for interacting with lighting: supporting and structuring learning activities; communicating with light and involving students; influencing the activity level and behaviour of students; creating a particular atmosphere; supporting visual tasks and visual comfort. All these motivational aspects should be considered when designing dynamic lighting systems for learning environments, helping to establish a new interactive tool for teachers.

Keywords: interactive lighting, dynamic lighting, lighting design, learning environment, teaching tool, field study, interaction, user-centric design

1 Introduction

According to the Danish Ministry of Education, students spend 13,000 hours at school [1]. Most of this time is in classrooms designed before the development of dynamic lighting technologies and digital devices such as smart boards and tablets. Neither the classrooms nor the lighting has been designed for the rapidly changing activities associated with different pedagogical approaches used today. Although this fact indicates the potential offered by tailor-made lighting scenarios for various learning situations, there is still a lack of knowledge on just how teachers might actually adopt and use these dynamic lighting applications as interactive tools for teaching.

1.1 Light for Learning

Previous studies have concluded that long-term exposure to blue-enriched light increases the academic performance, concentration and progression of students – especially during lessons in the morning [3, 4, 5, 6, 7, 8]. However, studies using academic performance as a test parameter reveal a contradiction between findings from field studies and controlled experiments [2]. Other studies indicate that exposure to warm light can reduce aggression and positively affect social behaviour [7, 8, 9], but there is a clear need to focus on the requirements of users through a more holistic approach to research. As a result, this field study uses a holistic methodology in which several factors – as well as the relations between them – are studied to reveal how teachers interact with light in classrooms and the specific motivations behind these interactions.

This paper presents the results of a case study looking at interactive lighting in classrooms. A new lighting system with the option to choose different lighting scenarios was installed in three classrooms in a Danish elementary school. An analysis of the classroom environment was carried out in 2016, prior to the evaluation, looking at the needs of teachers and students and the effects of the existing lighting on student behaviour [10]. Based on this evaluation, four different dynamic lighting scenarios were defined. These were then implemented in the classrooms and assessed during the final test phase of the research project in 2017. It was hypothesised that the lighting scenarios would help teachers structure their teaching.

The objective of this paper is to present and assess how dynamic lighting can be used as a tool for teachers to “set the scene” and thereby support different learning activities by asking two key questions:
Is there a relationship between the teachers’ usage of lighting and the classroom activities? Which motivations influence the way these lighting scenarios are used?

2 Methods and Materials

The research focuses on light as experienced in the classroom, meaning that both daylight and artificial light have been taken into account. A field study was carried out using a mixed-methods approach [11,12] combining quantitative data with quali-tative information to create a full understanding of the way teachers interact with the lighting. While the non-participatory observations and structured data-log from the lighting control system helped researchers understand how staff actually used the new lighting system, the interviews provided a useful insight into the personal experiences of the teachers.

2.1 Research Setting and Lighting Scenarios

The field study setting consisted of three classrooms with windows on one side of the room. The renovation of the rooms involved replacing florescent-tube ceiling luminaires with controllable LED lighting. The lighting scenarios were designated as follows: Standard, Smart Board, Fresh and Relax.

Ceiling luminaires	300 lx / 3500 K
Board luminaires	500 lx / 3000 K
Wall washers	off

Ceiling luminaires	300 lx / 3500 K (one above SB off)
Board luminaires	300 lx / 3000 K
Wall washers	300 lx / 4000 K

Ceiling luminaires	500 lx / 5000 K
Board luminaires	500 lx / 3000 K
Wall washers	420 lx / 4000 K

Ceiling luminaires	100 lx / 3000 K
Board luminaires	300 lx / 3000 K
Wall washers	75 lx / 4000 K

Figure 1. The illuminance level and correlated colour temperatures of the different luminaire groups used to create the four lighting scenarios

Teachers could select one of these scenarios or switch off the luminaires completely, while also having the option to manually adjust the CCT (Correlated Colour Temperature) and illuminance (lux level) of each scenario. The Standard scenario was designed to fulfil the requirements of the DS/EN 12464-1 DKNA standard. The primary aim of the Smart Board scenario was to simultaneously stop artificial light weakening the contrast of the projected image and allow students to perform tasks at their desks. The Fresh scenario was intended to "freshen up" the students and to increase alertness, while also focusing attention on the teacher or the task. Finally, the Relax scenario was planned to create a relaxing and informal atmosphere in the classroom by providing warm, dimmed lighting.

2.2 Data Collection and Analysis Methods

The data was collected over three and half months from 4th September to 15th December 2017 and included quantitative data from the lighting system's data-log and qualitative information gathered during interviews and observations conducted over two shorter periods, which each lasted a few weeks. The participants were teachers and the school children of three classes: X, Y and Z. Each classroom between 22 and 24 children aged 11 to 12. The three classes each had a main teacher (all of whom were female), with five additional rotating teachers (two females and three males). One female teacher was in her fifties, but all the other teachers were in their thirties.

2.2.1 Quantitative Data: Lighting Control Data-log

The lighting system´s data-log provided quantitative data from 4th September to 15th December 2017. Absent data, day trips and holidays were excluded from the analysis. The data-log tracked the choice of lighting scenario and any manual adjustments of the lighting. The analysis covered the actual duration of each lighting scenario, calculated in minutes, as well as the instances of choice, calculated as the number of times a setting was chosen. The break periods were not factored into the duration analysis, but they were included in the number of instances. The total count was plotted against the week numbers to assess trends in usage. Week 42 and some single days have been left out of the analysis due to holidays, absence from classrooms or missing data.

2.2.2 Qualitative Data: Interviews and Observations

The first observations were carried out in 2017 in weeks 37 and 38, before the second round in weeks 48, 49 and 50. The observers focused on specific themes that were derived from the pre-refurbishment observations, but with the option to add further relevant information. While the data-log provided information about how teachers interacted with the lighting system, the observations detailed the reasons and motivations for their choice of scenario and how this affected student behaviour. The observations focussed on the way teachers interacted with the lighting during their lessons, while at the same time monitoring student behaviour and recording the activities that were taking place.

Semi-structured interviews [12] were conducted during September and repeated again in December with the same teachers to track their experiences and any changes in preference or opinion. These interviews addressed the experiences of teachers with the new lighting, their motivations for using the scenarios, how they adapted the lighting to suit their teaching strategies and any changes in student behaviour. As part of the research, eight teachers were observed and six participated in group interviews that were carried out with either two or four teachers. Group interviews (20-30 minutes) were conducted to allow the teachers to share their experiences with each other and to help generate a discussion [12].

2.2.3 Combining Quantitative and Qualitative Data

The data from the observations was separated into the main categories of teaching and learning activities using content analysis [12], before being organised into timelines specific to each teacher, to which personal lighting scenario choices from the data-log were also added. In this way, the duration of each lighting scenario and the specific activity could be evaluated together. These timelines enabled a comparison of the teachers' individual usage patterns of lighting scenarios and their corresponding activities. The timelines of three teachers (T1, T2 and T3) were chosen for further analysis and the relative usage of each lighting situation for certain activities was calculated as a percentage. These teachers were chosen due to the fact that their lessons had been observed in both autumn and winter and because their lessons featured all the activities of interest. Analysis of the interviews also features certain examples of the way other teachers used the lighting as a tool.

3 Results

On average, lighting scenarios in each classroom were chosen four times a day. This includes the option to switch off the luminaires completely or adjust them manually. Only lessons before lunch were included in the count. Usage increased in the beginning and then gradually declined to a steady level, before peaking in the final week. The increased use of the lighting scenarios in the first weeks of the study can be put down to curiosity about the new technology and a desire to experiment and play. As a teacher pointed out in one of the interviews, this novelty eventually wore off: "I am not aware of the light anymore. In the beginning it was exciting, but light does not play as big a role now. [...] There are 10,000 other things." [T2: 18/12/2017] Choosing a scene was not an automatic part of every teaching routine, nor their first priority. It was more the case that the teachers had to adapt the lighting scenes to their teaching strategies, the needs of students and their lessons.

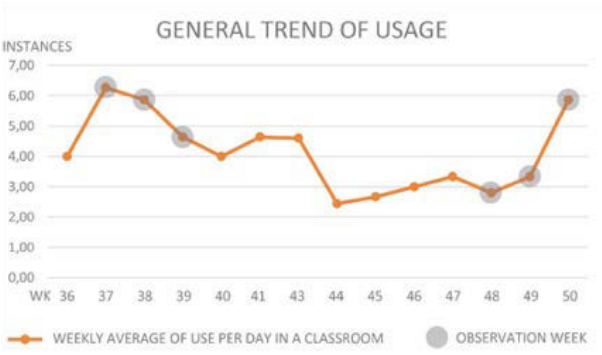

Figure 2. Weekly averages of daily use of lighting scenarios in a classroom. Repetitive rapid changes of lighting with intervals of just 1–60 seconds were counted as one instance.

The analysis identified that the usages of lighting scenarios was related to five different types of motivations.

3.1 Supporting and Structuring Learning Activities

Analysis of the classroom activities together with teachers' usage of lighting scenarios indicates that changes in terms of the lighting scenario during lessons often coincided with a change in activity. This was confirmed in the interviews with T3, who explained that the choice of lighting was related to the learning situation. On the other hand, T4 recalled that he only changed the lighting to suit the activity when he entered the classroom. He mostly only adjusted the lighting situation during the lesson if he wanted to show a video on the smart board or if someone had altered the settings while he was out of the classroom. The data clearly highlights the individual nature of teacher interaction with the lighting. A good example is the reading session (Figure 3), which involved students reading themselves or the teacher reading out loud. The following charts show that T1 preferred to use the Relax scenario, whereas T2 only selected the Fresh scenario and T3 mostly opted for the Standard scenario. However, T3 changed his preference towards the end of the year and started to use the Relax scenario for Christmas stories.

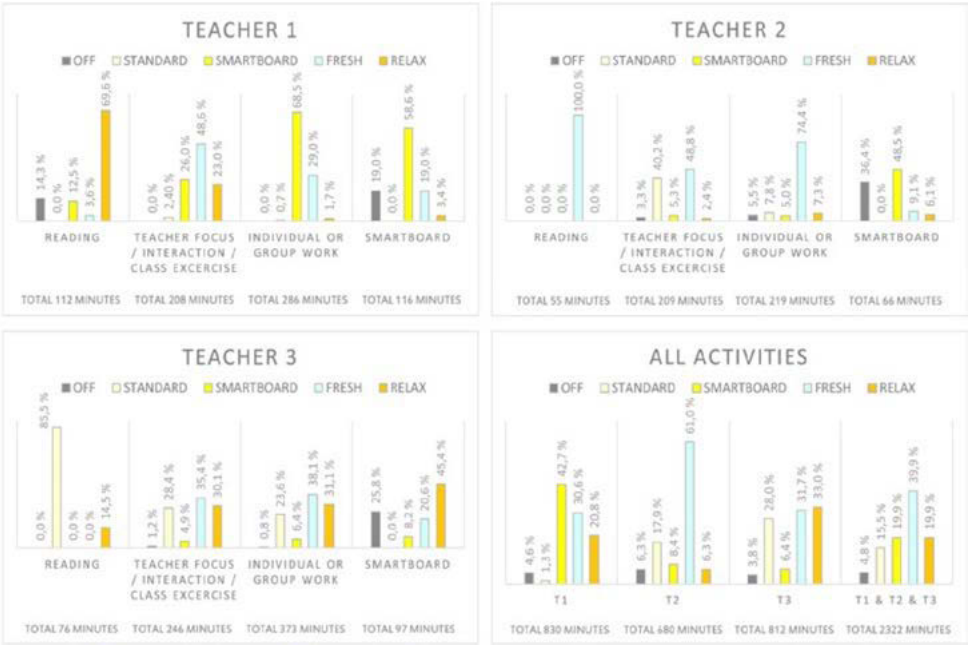

Figure 3. Relative number of lighting scenarios used by teachers during selected activities and in total.

T3 explained in an interview that his choices were related to differences in the learning situation. During religion lessons, students are allowed to leave the classroom and work on their assignments somewhere else. Students coming and going can lead to significant interruptions. T3 preferred to use either the Standard or the Fresh scenario for these kinds of situations, as he found them stimulating. He explained that the Relax scenario, which he preferred for mathematics lessons when students remain in the classroom and work alone or in small groups, would be ill-suited for these kinds of active sessions, because the students now associate mathematics with a calm and undisturbed learning environment. The teacher described the interactive relationship between learning activities and lighting as follows: *"Each activity has its scenario. […] the [learning] scenarios influence the lighting and the lighting influences [learning] scenarios that take place."* [T3: 15/12/2017] Alongside the motivation to support a certain activity with an adequate lighting scenario, there was equally an incentive to use lighting as a tool to structure learning activities. During the interview, T3 explained that he also used the lighting to signal the start of a new activity, like when students have to read something. As such, the choice of lighting scenarios depended more on the learning activity and less on the actual subject. T3 also referred to a new pedagogical approach in teaching that promotes dynamism in school work by encouraging changing activities and working methods: *"A lot of the improvement results in teaching that becomes more dynamic and is not uniform and boring for the children. That you are also able to change the lighting scenes at the same time does not mean that the children sit still that day. And it is not the great acoustic panels that make the children stay calm. But it means that the children will have some of these funny changes [during the day] and that matters."* [T3: 15th December 2017]

3.2 Communicating with Lighting and Involving Students

The example of T3 using light to signal a change of activity shows that lighting can be used as a tool to communicate with students. During the September observations, T4 was seen to use a similar way of structuring lessons by changing the lighting. He also communicated his lighting choice verbally to the students in order to clearly announce the change. Based on both the observations and the interviews, it could be noted that teachers involved students in their lighting interaction and asked which particular lighting scenario they would prefer. Young people often made spontaneous comments about the lighting, as well as requests, to which the teachers responded by adjusting the lighting. After becoming familiar with the new level of flexibility, students would sometimes remind teachers to change the light for a certain activity if and when they happened to forget.

3.3 Influencing the Activity Level and Behaviour of Students

Lighting was also used to try and influence the activity levels and behaviour of students. For example, T4 used the Fresh scenario to let students know that they should focus, while T2 and T5 related their lighting interaction to the energy levels of students. They explained that if the atmosphere in the classroom was too energised, they would switch to the Relax scenario to settle the students. According to their experience, this worked well. At the same time, T3 chose not to use the lighting to make students calmer when they were noisy, because students only see the light and do not hear it. An acoustic signal was required to stop any off-topic behaviour. In addition, the interviews with T3 and T4 in December indicated that it was very difficult to gauge the effect of the lighting and to judge the effectiveness of other factors in the refurbished classrooms (such as the new acoustic panels). In addition, the students had matured by one year and there had been changes in the way the groups were formed.

3.4 Creating Atmospheres

One specific motivation behind using lighting as a tool was to create the right atmosphere for the specific learning situation or particular activity. This was sometimes linked to the maturity level of the group. T3 explained in the second interview that he chose the Relax scenario and manually dimmed it further to create a really cosy atmosphere when reading a Christmas story to the class. In the second interview, T4 explained that he thought more about the maturity level of the class than the specific learning situation. For this purpose, light with warm tones was chosen to generate a cosy atmosphere and therefore a comfortable learning environment for any students who were lagging behind. T4 used manual adjustments to try and create a lighting situation that combined appropriate levels of illuminance with a warm CCT, as this kind of scenario was missing from the list of scenarios. The analysis revealed some seasonal variation in terms of the preferred scenarios. As winter approached, the preferred CCT shifted towards warmer tones and illuminance levels decreased as the level of natural light dipped. This is proved by increases in the use of the Relax scenario. Both T3 and T4 explained in the winter interviews that they now used warmer options, which they sometimes manually adjusted to even lower colour-temperature settings. T4 related this choice of a warm scenario to the natural-light situation outside, as well as to the high contrast between inside and outside that occurs during the darker time of year. Although it was beyond the scope of this study, the correlation between the use of scenarios and seasonal daylight conditions is an interesting preliminary finding and certainly one that is worth investigating further using statistical methods.

3.5 Supporting Visual Tasks and Influencing Visual Comfort

Finally, teachers interacted with the lighting to create suitable lighting conditions that supported visual tasks and helped maintain visual comfort. Most of the time this was achieved by using the manual override of blinds or by drawing the curtains to reduce glare caused by direct sunlight. These methods were also employed to increase the visibility of the smart board.

The graph in Figure 3 shows that the Smart Board scenario was often chosen when the smart board was in use. However, teachers were sometimes critical of this scenario in the interviews. Several claimed that the scenario did not ensure good visibility of the smart board and were of the opinion that the round ceiling luminaires should have been turned off – not just the fittings in the middle. Teachers solved the visibility issue by either choosing the Relax scenario (T3), with its lower lighting levels, or by turning the luminaires off completely (T2 and T4).

4 Discussion & Conclusion

By applying mixed methods, the findings of this study demonstrate how the visual effects related to comfort and visibility play a key role in both the teachers' and students' sense of well-being and satisfaction. While preferences in terms of lighting scenes have previously been assessed in laboratory tests [2], this study contributes to existing knowledge [2, 4, 5, 14] by conducting analysis using a field study that features daylight as a co-founding factor.

The preliminary study conducted before the refurbishment of the classrooms showed that light was a subconscious part of everyday classroom management. In contrast, the evaluation of the way teachers interact with the dynamic lighting proved that teachers had become aware of both how they use the lighting and – as a consequence – the possibilities associated with using lighting as a tool.
A comparison between the choice of lighting scenarios and the learning activities revealed a relationship between these factors: teachers chose lighting scenarios and adjusted the lighting to support activities and structure lessons. However, the manner in which the lighting scenarios were used (i.e. which scenario was selected for which activity) was very much teacher-specific, based on personal taste and individual pedagogical approaches.
The sample size for this study was small: three case-study teachers and five other teachers were observed for five weeks. Further studies with a larger group of teachers and a longer observation period combined with statistical analysis might also reveal some general patterns and correlations between the chosen lighting scenarios and teaching activities, in addition to the individual preferences.
Analysis of the interviews and observations showed that different strategies were employed. Teachers were aware of how the scenes shaped particular behaviour and – according to their experiences – the lighting certainly had an effect. Furthermore, the analysis also demonstrated that the teachers were keen to influence student behaviour throughout the day by adjusting the lighting situation in line with changes in activity. As the findings show, seasonal changes were also a co-founding factor in the way teachers looked to generate certain atmospheres. This is shown by the increased use of the Relax scene while reading Christmas stories or by the number of times the lighting was switched off when students were watching Christmas shows.
The observations revealed that students were partly decision-makers in the choice of lighting scenarios. Either the teachers involved them actively when they chose a scenario or the students would make spontaneous suggestions. In this way, the students became co-creators in defining suitable classroom spaces and could be seen as decision-makers in selecting what they believed to be an optimal learning environment for particular tasks. The four lighting scenarios can therefore be regarded as tools that promote interaction between students and teachers. Becoming participants in the design of learning environments can influence motivation levels: *"Improving the congruence between the per-*

spectives of students and those creating the learning environment (i.e., teachers and instructional designers), thus, is likely to improve student learning" [13].
As indicated in the interviews, one of the reasons that the lighting system was used less after the initial period can be put down to the busy schedules during teaching sessions. The lighting, which was not necessarily a teacher`s main priority and was not part of the lesson planning, tended to be used somewhat spontaneously. As such, it is worth rethinking the design by considering a more autonomous lighting system. However, previous research argues that a hybrid between a full autonomous system and manual control is most desirable, as providing users with the option to manually change the lighting has a positive effect on both their well-being and comfort [15]. Based on this knowledge, the balance between a completely automated system and interactive control should certainly be considered.

In conclusion, this research has illustrated how lighting can become an integrated part of future pedagogic approaches. Five motivations for using lighting as a tool to support teaching have been identified:

- Supporting and structuring learning activities
- Communicating through lighting and involving students
- Influencing the activity level and behaviour of students
- Creating atmospheres
- Helping with the completion of visual tasks and boosting visual comfort

We argue that these motivations should be taken into account when designing interactive systems for the dynamic control of lighting in classrooms. Results show that each teacher follows a personal pattern and uses lighting as a tool in an individual way. Any system should therefore enable and support this versatility and adaptability. Alongside the potential for interaction, a self-learning system with greater automation could prove useful for less-motivated teachers, while also reflecting seasonal changes in the amount of available daylight.
These findings also raise the issue of whether classroom lighting in the future should be designed not only according to the DS/EN Standards for Lighting, but also whether it should be more closely aligned with user requirements for different lighting in classroom environments. For example, this could involve creating lighting typologies and scenarios that enable teachers to give a feeling of space and generate atmospheres as part of their daily practices. This study also underlines the importance of evaluating solutions after the initial implementation phase in order to make sure that lighting design schemes really meet the needs of users – both in theory and in practice.

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References

1. Undervisningsministeriet, https://www.uvm.dk/statistik/grundskolen/elever/elevtal-i-grundskolen. https://www.uvm.dk/folkeskolen/fag-timetal-og-overgange/undervisningens-samlede-laengde, last accessed 2017/12/14.

2. Hansen, E. K. Louring Nielsen, S. M. Georgieva, D. & Schledermann., K. M.: The Impact of Dynamic Lighting in Classrooms. A review on Methods. Institute for Computer Sciences, Social Informatics, Telecommunications Engineering 2018. ArtsIT 2017/DLI 2017, LNICST 229, pp. 314-323 (2018)

3. Barkmann, C., Wessolowski N., and Schulte-Markwort, M. Applicability and efficacy of variable light in schools. Physiol. Behav. 105, 621-627 (2012)

4. Mott, M.S., Robinson, D.H., Walden, A., Burnette, J., Rutherford, A.S.: Illuminating the effects of dynamic lighting on student learning. SAGE Open 2012, 1-9 (2012)

5. Sleegers, P.J.C., Moolenaar, N.M., Galetzka, M., Pruyn, A., Sarroukh, B.E., van der Zande, B.: Lighting affects students' concentration positively: findings from three dutch studies. Lighting Res. Technol. 45, 159–175 (2013)

6. Keis, O., Helbig, H., Streb, J., Hille, K.: Influence of blue-enriched classroom lighting on students' cognitive performance. Trends Neurosci. Educ. 3, 8–92 (2014)

7. Choi, K., Suk, H.J.: Dynamic lighting system for the learning environment: performance of elementary students. Opt. Soc. Am. (OSA), 24(10) (2016)

8. Wessolowski, N., Koenig, H., Schulte-Markwort, M., Barkmann, C.: The effect of variable light on the fidgetiness and social behavior of pupils in school. J. Environ. Psychol. 39, 101–108 (2014))

9. BRANZ Ltd.: Designing Quality Learning Spaces: Lighting. New Zealand: Ministry of Education (2007). ISBN 0-478-13619-6; WEB ISBN 0-478-13624-2

10. Georgieva, D. Schledermann, K. M. Louring Nielsen, S. M. & Hansen, E. K. (2018): Designing User Centred Intelligent Classroom Lighting. Institute for Computer Sciences, Social Informatics, Telecommunications Engineering 2018. ArtsIT 2017/DLI 2017, LNICST 229, pp. 314-323 (2018)

11. Creswell, J.W.: Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, 4th ed. SAGE Publications Inc., USA (2014)

12. Bryman, A.: Social Research Methods, 4th ed. Oxford University Press, New York (2012)

13. Könings, K. D., Seidel, T., & van Merriënboer, J. J. G. Participatory design of learning environments: integrating perspectives of students, teachers, and designers. Instr Sci, 42(1–9). (2014)

14. van Someren, K.L., Beaman, C. P. and Shao, L.: Users' experience of lighting controls: A case-study. Lighting Res. Technol. 2017; 0: 1–16 (2017)

15. van Essen H, Offermans S & Eggen B: Exploring the Role of Autonomous System Behavior in Lighting Control. In: Proceedings of Designing Interactive Lighting workshop at DIS 12, Newcastle, Great Britain (2012)