Designing User Centred Intelligent Classroom Lighting

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Abstract. Through a case study, this paper presents a new way of designing intelligent classroom lighting to meet the users' needs. A mix of ethnographic methods (field observations and interviews) were used to investigate the everyday learning activities at a middle school in Copenhagen in order to determine how lighting can support the learning environment. Based on the investigations, lighting design criteria and three predefined lighting scenes are proposed as a new design for meeting the needs of students and teachers during three types of activities. The scenes focus on smartboard visibility and on creating a visual focus on the teacher who is the centre of attention during most activities. It is hypothesised that if the scenes are used according to the different types of activities this would enable the teacher to create structure in the lessons and through this improve the behaviour of the students.

Keywords: Lighting for learning · Design research
User centred lighting design · Learning environment · Intelligent lighting
Design methodologies · Design of innovative learning environments

1 Introduction and Background

The aim of this paper is to present how a qualitative approach to investigating the needs of the students and teachers can be beneficial for developing intelligent user-centred classroom lighting. The paper will illustrate how understanding the needs and issues faced by the users in their current environment can be translated into design criteria for classroom lighting to support them in the process of learning and their daily school activities. This is especially important to consider when working with complex environments, such as learning environments of the 21st century, which need to be supported by flexible lighting systems.

The development of intelligent lighting has led to new possibilities for supporting classroom occupants in their daily activities. New LED technologies can provide users with the possibility to change gradually the intensity, distribution, and colour of the light, to separate the room easily into zones, to choose from predefined settings which the teacher or students can activate with one press of a button. Additionally, such systems allow for reprogramming of the lighting as many times as needed after the installation of the luminaires. This makes the job of a lighting designer and the

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decisions they face much more complex, as their designs can be much more flexible and can have greater impact on the learning environment than lighting installed just a few years ago. Such solutions are becoming increasingly common with the advancement of technologies, thus it is important to understand how they can support the needs of teachers and students.

Research on the effects of light on cognitive performance shows that higher correlated colour temperature (CCT) positively affects reading [1] and concentration [2]. According to other studies, lower CCT positively affects prosocial and aggressive behaviour, and fidgetiness [3], and is also recommended for students with special educational needs [4]. Additionally, Xu and Labroo [5] and Baron et al. [6] found that brightness has an effect on the strength of affective responses. Intelligent lighting provides the opportunity to combine all light parameters, such as CCT, intensity, and distribution, in various ways when creating advanced innovative systems to influence learning and classroom activities, which makes its effects and design much more complex than standard classroom lighting.

These new opportunities of using advanced technologies in the learning environment come at the same time as the introduction of new school reforms and teaching tools, such as interactive boards. For example, a school reform was implemented in Denmark in 2014 [7], and as consequence students and teachers have to spend more time in classrooms. Additionally, it suggests that the classroom activities are more diverse, including physical ones. Due to these demands, there is a need for a physical environment which should be easily modified throughout the day and fitting the constantly changing tasks [8]. Nowadays many more tools are available for students and teachers to use, such as smartboards and other interactive boards, laptops, and tablets. This makes proper visibility very important as glare has to be avoided for projectors and for various types of displays (as discussed by Ramasoot and Fotios [9]).

This growing complexity of technologies and learning environments calls for an innovative way of designing these environments, and therefore an adjusted design process. The aim of this paper is to address how involving the users in the design process through qualitative research methods can be beneficial for developing lighting design solutions which meet the needs of students and teachers of 21st century classrooms. This paper addresses a case study at a Copenhagen school which was about to be renovated with an intelligent lighting system, and was done in the classrooms before they were renovated. In this initial phase of the research project, before the classrooms were renovated or the lighting system designed, the authors were asked to conduct investigations of the users' needs and to define design criteria and a concept based on them. During summer 2017 the classrooms were renovated and intelligent lighting was installed based on the criteria defined in this project. The renovated classrooms are being tested in a later project.

2 Method

In this case study, the needs of the users regarding lighting were explored through analysing *how they used the space and light* and *what issues they faced*, through a mix of ethnographic methods. Qualitative methods were used as they have the advantage of

putting the designer, as a researcher, in the actual environment they design for and close to the daily lives of their users [10, p. 24]. This can be beneficial for developing an empathetic relation with the users, which is important for innovation (discussed by Liedtka and Ogilvie [11]), as well as for imagining how their designs would actually be used based on what they see in the current environment.

2.1 Field Observations

For this project it was important to understand the flow of a school day and the classroom activities, as well as how the occupants use the space and the light, in order to recognise the potentials for supporting the students and teachers through intelligent lighting. For this purpose, semi-structured observations were conducted. The observation guides had two main categories: *Light & use of the light* and *Activities & use of the space*. Photographs were also taken in order to track the changes in light and space occupation throughout the day, as well as the types of activities. This was meant to support the field notes taken during observations.

2.2 Interviews

Interviews were conducted to provide an understanding of how the participants subjectively experienced the space and how they used it throughout the year. Two guides, one for individual teacher interviews and one for student focus group interviews [10, pp. 73–77], were formulated. The guides included questions about their typical school day and issues they face when teaching or studying with respects to their environment, including the light. A semi-structured, as opposed to structured guides, enabled flexibility and the possibility to adjust the course of the interviews according to the questions which emerged [12].

3 Data Collection

The data was collected over two weeks in October 2016 (Table 1). The interview and observation data were collected simultaneously by two researchers, based on the availability of the students and teachers throughout the seven days of the field study. The classes for participation were chosen by the school administration. Two rooms were selected - one 5th grade to the east and one to the west. The teachers were

Table 1. Data collected during the field study.

Type of data	Count
Individual interviews	Three teachers, teaching language, mathematics, and music classes
Focus group interviews with 2–3 students	19 students
Field observations	Seven school days
Photos and times lapses	Seven times lapses, 280 photos

recruited based on convenience, according to who wanted to participate and when they were available [10]. All participants were kept anonymous throughout this study.

4 Findings

The data analysed include field notes, interviews, and photographs, which were additionally made into time lapses. The analysis aimed at contributing to the development of user-centred lighting scenes for supporting the everyday needs of students and teachers. In the following section the most relevant findings are presented.

4.1 Light and Use of the Light

At the beginning of the analysis, it quickly became obvious that the main issue caused by inappropriate lighting was glare on the smartboards. This was a pressing issue as the smartboards were used very frequently in both rooms. This problem led to the students and teachers either (1) blocking the daylight and turning off the artificial light in order to be able to see properly, or (2) leaving the lighting as it was to prevent the students from becoming sleepy and losing their focus. This issue was observed by the researchers and shared by one of the teachers who stated that she preferred to leave the lights on for supporting the students' alertness even if it caused glare. Therefore, the teachers were forced to choose between these two options, both of which were preventing them from teaching and learning in the most efficient and desirable way.

Based on the time lapses it was evident that there were only minor differences in the ambient brightness throughout the day and that the rooms were very evenly lit. This was regardless of whether the main source of light was natural or artificial. It was also evident that the CCT remained mostly constant - the exception was in the early mornings when the main source of light was the fluorescent lighting and the rooms were perceived as being more yellow. This even and consistent lighting was in contrast to the rapidly changing classroom activities and the needs of the occupants.

4.2 Activities and Use of the Space

It was observed that different subjects required different use of the rooms. In language classes students would mostly have discussions and read and write on paper, while in mathematics classes they would more often use the smartboard and the whiteboard in combination with laptops. However, observations of the same subjects led by different teachers showed difference in, for example, what percentage of the time a teaching tool, such as the smartboard or books, would be used. Additionally, in the subject Supported Learning the activities were different each time: doing homework, watching a movie, completing a crafts assignment. Nevertheless, the teacher being the centre of attention was consistent between most tasks: when solving a mathematic problem, music activities, or reading. Another consistency between subjects was observed in the furniture arrangement, which was not dependent on the activities, but was instead changed every other month.

From an observer perspective, the biggest surprise was that the students were using the rooms very actively and often unpredictably during lessons. Additionally, change between different activities, such as reading, writing, using smartboard, whiteboard, or paper was rapid most of the time, and a lot of the time multiple tools were used simultaneously. Due to this rapid change, which was also leading to different use of the space, changes in the students' behaviour and in their concentration, it was sometimes very difficult for an observer to distinguish between lessons and breaks.

5 Discussion

5.1 Defining Design Criteria and Lighting Scenes

Based on the findings, design criteria for meeting the users' needs were formulated (Table 2) and three predefined lighting scenes were proposed (Fig. 1). It was concluded based on the analysis that the main focus of the design should be (1) *to improve the visual comfort during classroom activities, especially in respect to the smartboard,* and (2) *to direct the students' attention to where the activities required it to be* - e.g., teacher or smartboard – in order to provide the teachers with *a tool for structuring the classroom activities*. The main findings contributing to this design proposal were that the smartboard was used frequently but glare was often a problem; and that teachers were the focus of students' attention, but that this is not indicated visually due to the evenly distributed lighting.

Table 2. Design and success criteria for the user-centred intelligent lighting scenes.

Design criteria	Success criteria
1. High visibility of the smartboard projection without the need to turn off the artificial lighting	1. The students and teachers do not express glare issues from the artificial light during interviews and it is not observed that they turn off the lighting when showing something important on the smartboard
2. Possibility for creating a visual focus on the teacher in the front part of the room through lighting	2. The teachers express and it is observed that they use the lighting for creating focus in the front part of the room when the students need to direct their attention there, and not during activities when the students work individually or in groups, where they are focused on their desks

In addition to the analysis presented in the previous section, criteria were also developed through (1) describing each activity that was taking place in regular classrooms during observations; (2) setting lighting criteria for each activity; and (3) grouping the activities into types according to the lighting which is needed. Three types of activities emerged from that analysis and a scene was proposed for each of them: *Watching a video*, *Focus on teacher*, and *General lighting* (Fig. 1).

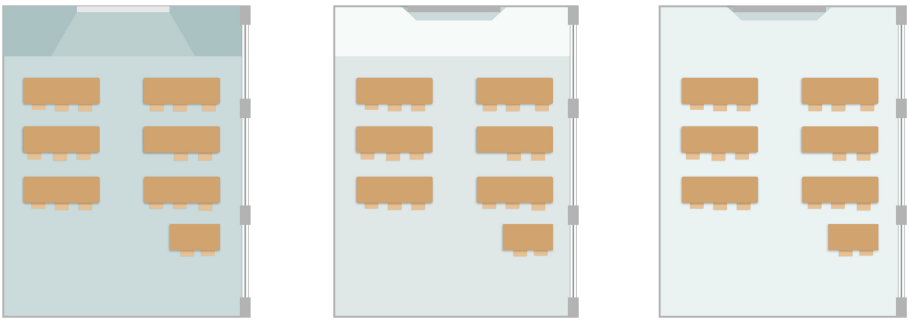

Fig. 1. Concept for the three predefined lighting scenes. The different shades represent different levels of illumination.

The *first* predefined lighting scene is based on the finding that the smartboard is used a lot, but disability glare is an issue. It was also found that the students and teachers prefer to have bright light throughout the day in order to stay alert. It is proposed that the light in the front part of the room is switched off while the rest of the room is still lit up, although to a lesser extent compared to the other scenes (Fig. 1). This would be most appropriate to use when the students are watching a video for a long period of time; as for instance observed in the class Supported Learning.

The *second* scene is based on the finding that while the teachers are the centre of attention during most activities there is no visual focus on them, since the room is evenly lit. In stage lighting, one of the most commonly used tools for drawing the eye of the audience is to create visual focus through bright light, as 'the human eye is naturally drawn to the brightest part of any composition' [13, p. 194], which is also pointed out by Descottes and Ramos [14, p. 58]. As shown in the illustration (Fig. 1), the design of the second scene suggests that there is a visual focus on the teacher and the front part of the room, which could be achieved through using different light intensity levels in the front and back, possibly supported by different colour temperature, distribution of the light, and/or different types of luminaires. This lighting scene would be appropriate for when the teacher is, for example, introducing an exercise or leading a discussion. However, although it is known that bright light catches the attention initially, more research is needed to determine whether the focus of the students would be sustained for long periods of time through this approach.

The *third* lighting scene proposes general, even lighting in the room (Fig. 1), which would be appropriate during the varied and complex activities which were observed during the field observations, such as when doing a crafts assignment and other types of individual or group work, or a mix of these. These would typically be activities during which the students' attention is not only needed in the direction of the teacher's desk or the boards, but is changing in relation to a combination of activities. It also suggests the highest illuminance of all the scenes as it is probable that the students would need to work more closely on details.

A common recommendation for the three scenes is that the smartboard receives as little light as possible. This is important due to the finding that it is used very often, including for short periods of time - as little as two minutes. Therefore, it should not be assumed that the teachers would adjust the lighting every time a short video or an image is shown.

Additionally, a hypothesis is suggested that the three scenes would serve as a teaching tool by enabling the teacher to create structure in the classroom activities. As during the field study there were only minor changes in brightness and CCT throughout the day, these predefined settings, if used regularly, could support creating a rhythm in the activities through the change in light, and showing the students what is expected of them. Multiple sources discuss the effectiveness of using non-verbal cues for letting students, including ones with ADHD, autism, and other learning disabilities, know what is expected of them at that moment [15–17]. Doerries and Grosser for example state: 'verbal or nonverbal teacher cues signalling upcoming transitions help prepare students for changes in activities or lessons' [17, p. 5]. CASTL similarly point out: 'Cues and visuals work because they quickly and efficiently remind children what behaviours are expected of them' [16, p. 1].

Before the lighting was installed in the classrooms, the concept behind the scenes was introduced to the teachers who pointed out the need for a simple and easy to use system. The teachers only proposed few suggestions, indicating that they need to use the system and get familiar with the functions before they can propose adjustments or changes. Therefore, the design is kept uncomplicated in order to see how the teachers and students will react to it and use it. Although there would be some limitations when changing the settings, the lighting could be made more advanced in future if it is seen or expressed by the occupants that they would prefer more flexibility.

5.2 Limitations of the Methods Used

Observations were conducted to investigate the classroom activities and behaviour, issues regarding the physical environment, as well as how the teachers and students interact with it. Photos and time lapses were important for following the changes in the space and activities more objectively and precisely than through field notes. The personal and mechanical observations were supported with interviews, which contributed to understanding how the students and teachers experience the space, and specific examples of their needs and issues. The interviews were also important for acquiring information about the use and experience of classrooms throughout the year, which is impossible to observe within a short study.

These qualitative methods were useful for avoiding preconceptions of how lessons are conducted and what activities take place in regular classrooms. For example, in the beginning it was assumed that it would be possible to have different lighting distribution based on the activities, as each would have a different furniture arrangement. However, it was found that the arrangement does not depend on the activities taking place. Similarly, an assumption was made that the lighting scenes could be based on the subjects, and each scene would be useful for only some subjects. However, only through conducting field observations it was possible to see that, although there are some differences between how the space is used between subjects, these were too teacher-specific. Therefore, qualitative

methods were useful for removing preconceptions and creating knowledge on what activities the environment should be designed for.

Interviews were also relevant for supporting the observations by confirming what is important for the students and teachers during lessons. For example, through field observations a conclusion was reached that there were glare issues with the smartboard, but it was possible that the occupants actually did not experience problems. However, the interviews confirmed this finding and its importance.

A downside to the methods used is that they are time-consuming [10, p. 25] and only limited amount of data were gathered: two classes from the same grade and three teachers participated. It is however possible that other grades and teachers have different experiences and needs. This issue could be overcome by supplementing these methods with other methods: for example questionnaires, which would allow for faster collection of data from more individuals.

5.3 Design Evaluation

As part of the next phase of this project, a renovation of four classrooms, including renovation of the lighting, was carried out in the summer of 2017.

Before the new lighting solution was installed, an additional exploratory research study was carried out by the researchers. Here, ten *other* intelligent lighting solutions in Scandinavian classrooms were studied, including how the teachers experience two of them, both located in Copenhagen and designed within the last five years. The research was done in order to investigate whether these solutions already installed at other schools meet the needs of the users. It was found that solutions similar to the presented proposal, such as focusing on smartboard visibility and on creating a visual focus on the teacher, have not been installed. It was also found that the users are rarely involved in the design process, especially in the beginning when design criteria are defined. The teachers at such schools expressed that visibility of the interactive boards is an issue, causing students to become distracted as they are not able to follow the lessons. Therefore, the design criteria and lighting scenes presented as the outcome of this research show to be unique in the field of classroom lighting, and an evaluation of the lighting installation is important for understanding the *effectiveness of applying qualitative methods in lighting design research*.

The evaluation of the lighting is planned for September and December 2017. It will be carried out through a similar methodology and will investigate whether the lighting supports the criteria and the needs of the users in practice. To analyse how the teachers adjust the lights and window shading according to the students' needs and behaviour, and according to the classroom activities, observations and focus group interviews have been planned. In addition to the methods already used, manual adjustments of the lighting will be tracked automatically during the evaluation, through a datalog. While observations will explain the context of the choice of light, automatic tracking of the light will provide the precise time of the changes and what settings are chosen. During the evaluation it will also be explored through measurements of the general sound levels in the classrooms whether the lighting can be used as a tool by the teachers to influence the level of activity noise during tasks.

5.4 Future Work

Currently, at the case study school the teachers often request from the students to control the artificial light and the curtains. After the implementation of an intelligent system, the teachers would probably have the main responsibility of adjusting the light. However, a risk emerges in this regard since during this study it was observed that the light was adjusted often randomly: e.g., the occupants would close the curtains to watch a video but would not open them again right after its end. Predicting the use of the system and designing it according to these predictions is especially important, since if the lighting is not used in the way intended by the designers, its effects might be undesirable or it might simply be useless.

Furthermore, the knowledge from this project can be used in future research to investigate how lighting can be used as a teaching tool for creating structure, in studies also integrating knowledge from a pedagogical perspective.

6 General Conclusion

This study investigated how the needs of students and teachers regarding lighting can be explored; and how this can be useful in the process of developing innovative intelligent lighting solutions for classrooms. A need for a qualitative approach was recognised and, as an outcome of the study, design criteria and intelligent lighting scenes were developed to be implemented and evaluated at a Copenhagen school.

This paper suggests a different approach to designing classroom lighting, namely involving the users and understanding their needs in order to define the design criteria for intelligent lighting systems. This is achieved not only through focusing on how users experience the lighting and what issues they face in this regard, but also the activities they take part in, the tools they use, and what is important for them in their everyday teaching and learning situations. This way of doing design research was able to lead the designers in a direction that has not been taken before, according to the authors' research of existing solutions. Evaluation of the project after installation will show whether the students and teachers also experience that this lighting meets their needs in practice. It will also show whether the teachers would adopt the lighting as a teaching tool, and whether this would enable them to create structure in the classroom activities, thus improving the learning environment.

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