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Light4Health eLearning Course: health research for interior lighting design. Re-thinking design approaches based on science

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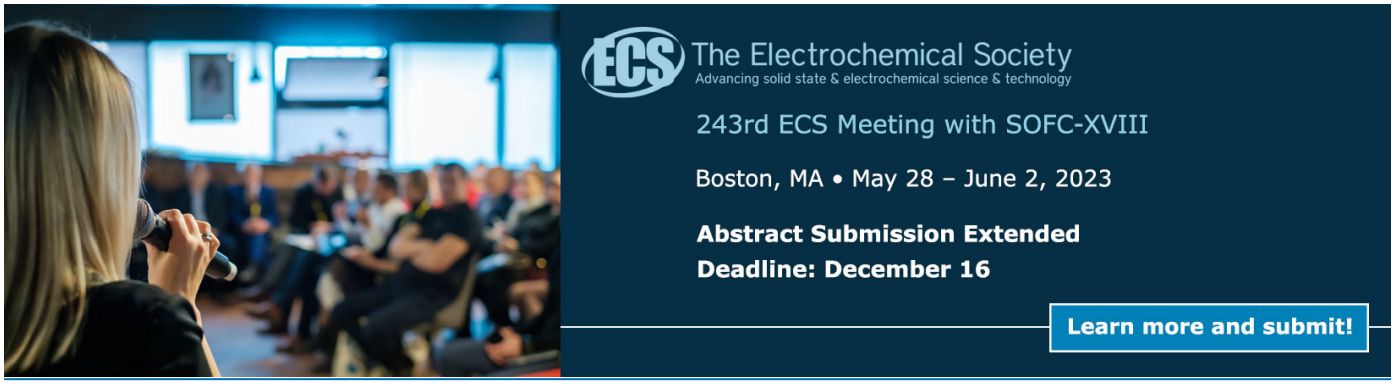

Light4Health eLearning Course: health research for interior lighting design. Re-thinking design approaches based on science

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Abstract. This paper presents the results of 'Light4Health' (L4H), a three-year EU Erasmus+ Strategic Partnership grant project (2019-2021), which investigated, systematized and taught health-related research on the impact of natural and artificial light on human health and well-being relevant to indoor lighting design. The objective was to re-think evidence-based lighting design approaches for residential, working/educational, and healthcare spaces, in order to develop a novel cross-disciplinary eLearning platform, that intersects lighting design and current peer-reviewed health research through a select combination of the most relevant research, methods, and tools. The content was developed through teaching workshops with international researchers, teachers, and students. Participating students were introduced to the application of relevant research and new metrics, in order to produce creative lighting design proposals. Students were able to inform lighting design approaches that support health and well-being without compromising creativity via the tools and methods developed through the health sciences. With this project, participants and consortium members have narrowed the gap that exists between research and the practice/application of lighting, by translating research from complex scientific jargon into various tools for designers to use. The knowledge gained, was consolidated into an open-access online curriculum for international lighting design students, educators and professionals via the free eLearning Moodle platform (https://course.light4health.net/).

1. Introduction

In 1935, the Swiss architect Le Corbusier was already highlighting "the struggle for light" as one of the emerging planning problems of the modern world [1]. Today, densely filled, tall buildings in cities mean access to daylight is even more restricted.

The invention of electric lighting allowed inhabitants to spend more time in enclosed spaces, in order to perform necessary visual tasks long after the sun set. Nevertheless, the latest research indicates that a lack of exposure to proper, quality light has immense effects on people's health, well-being, and

productivity [2-4]. Therefore, an unprecedented paradigm shift has been taking place in the lighting community, which involves moving beyond energy efficiency towards quality light for well-being, and from a vision/perception-oriented lighting approach to one that is also oriented towards human biology. The key application of health research knowledge in the lighting design profession, is for the development of lighting to be an element of preventive healthcare. It balances the visual, emotional and biological benefits of lighting on humans; promotes good vision, and simultaneously satisfies human emotional and biological needs; also taking into account that light stimulates biological effects on psychology and physiology. Given that every human is constantly exposed to light, the introduction of lighting that is based on research could have a significant social and economic impact for the EU and beyond.

Additionally, lighting practitioners, responsible for designing artificial lighting plans for indoor spaces, have been overwhelmed with recently developed health-related lighting metrics by scientists and researchers. Lighting practitioners require clear guidance on which metrics to apply and the reasons for applying them, in order to focus on making lighting safer and healthier [5]. The Health Research-Based Innovative Open Educational Resources and Tools for Lighting Design Students and Professionals LIGHT4HEALTH project was developed to respond to these challenges. Sponsored by Erasmus+, the intra-university project involved experts from Lighting Design, Light and Health Research, Neurology, Architecture, and the Built Environment from six internationally renowned institutions including the UK (University of Wolverhampton - UOW), Denmark (Aalborg University - AAU), Germany (Hochschule Wismar - HSW), Sweden (Royal Institute of Technology- KTH), Russia (ITMO University), and the USA (Thomas Jefferson University - TJU).

The first objective of this project was to re-think existing lighting design approaches for residential, working/educational, and healthcare spaces, by developing a cross-disciplinary eLearning platform, that incorporates information from current peer-reviewed health research into lighting design education via the selection of a combination of relevant and appropriate methods and tools. These were informed by evidence-based research in Neurology, Photobiology, Neuroendocrinology, Neurobehavioral Studies, Psychophysiology of Perception, as well as aspects of Environmental Psychology, which all aimed at fostering accessibility and the implementation of the curriculum across Europe and overseas. Researchers from Thomas Jefferson University's Light Research Program, which included Dr George Brainard and his team, joined this project as experts to advise on the physiological effects of light [5-9]. They also provided guidance on the use of appropriate lighting metrics, which includes tutorials on the use of CIE α-opic Toolbox [10]. Thanks to this knowledge, lighting professionals can be confident with science informed circadian protocols. Teachers from the partner universities were responsible for efforts that included the development of the curriculum, preparation of pre-recorded lectures and exercises, reviews of student's work, and the creation of a teachers' guide.

The second objective was to meet the growing needs of the lighting industry to fill the gap between research, education and application, and to better connect them. As there are significant growth and employment opportunities in the lighting sector that have not yet been undertaken, the lighting industry, together with EU legislators, aims for the growth of the European lighting market through more intelligent and human oriented lighting that supports health and well-being. At the same time, educational programs about this topic in Europe and overseas are falling behind, failing to produce the required number of graduates. To fulfill these needs, we developed the course content for students in graduate Lighting Design programs as well as professional lighting designers. The project envisaged the involvement of various groups, such as: students enrolled in summer school workshops, adult learners/practitioners, teachers in fields related to lighting design, developers of study programs, employers at the regional, national and European level, the lighting industry, education certification, healthcare authorities, and local communities/general public.

2. Research questions

Three key research questions were explored and investigated during the course development to achieve expected project objectives and to help position and operationalize the findings in relation to the following identified issues:

1. How to apply the outcomes of peer-reviewed research about the effects of light on human health and well-being to current design education via an opensource teaching platform?
2. What are the most appropriate metrics currently being used to measure the impact of light on health and well-being, specifically for indoor environments?
3. How to predict and evaluate whether an interior lighting design supports the well-being of users?

This paper focuses solely on the project and the implementation of knowledge, however it does not answer the specific design-related questions that have been investigated.

3. The general structure of the L4H eLearning course

This online course aims to bring the latest applicable health research findings to lighting design education. The three course goals are:

- Highlight the significance of physiological and psychological health research,
- Enhance the quality and relevance of participants' applicable knowledge and skills,
- Equip graduates with current and relevant research, design, and skills for the lighting industry.

The development of the L4H eLearning course consisted of five steps (Figure 1).

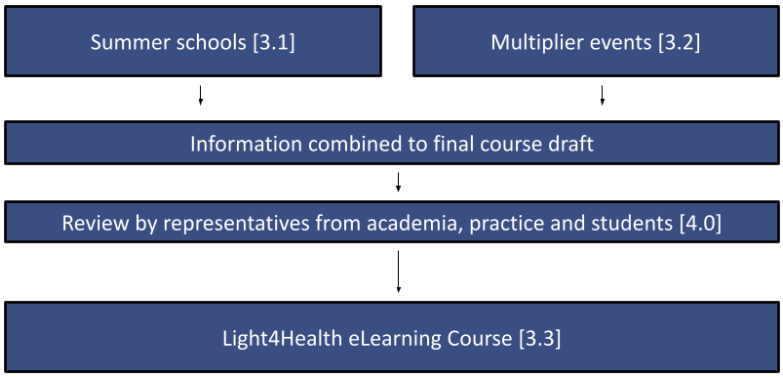

Figure 1. Overview of the L4H project

3.1. Summer Schools (Workshops)

Three innovative teaching modules were validated through test-runs in the format of transnational Summer Schools at partner organizations, resulting in first-hand experience and extensive feedback data to improve structure and navigability of the resulting eLearning platform. The workshops took place with a total of 91 students and 14+ teachers in various locations such as: Wolverhampton 2019 (in person); Hochschule Wismar 2020 (online and in person) and Aalborg University 2021 (online). All had different topics, timeframes, and due to the COVID-19 pandemic, it was necessary to shift from in-person summer schools to remote classes with different teaching methodologies (see Figure 2 for more information).

The workshops helped to develop curricular and applicable knowledge in both the conceptual and practical aspects of health research, as well as the lighting design for a variety of environments. Project

work was the central pillar of each of the schools. It served to structure the understanding of health research methods so that students could develop a critical approach to what is known about the impact of different lighting solutions on humans in specific environments. Students were introduced to new metrics and software for measuring and simulating possible impact on health, in order to then apply these methods in their design process and concepts. This required students to experiment with research methods and metrics in various settings, which allowed them the opportunity to conceptualize their ideas and consider appropriate design solutions. Additionally, interactive quizzes and sample task assignments were provided for each summer school module to assess the students' understanding of the material.
Feedback from the students at the end of each workshop helped to refine consecutive workshops and the eLearning platform.
Example comments:
"It was a really great opportunity for all of us lighting designers to attend such a valuable workshop like this. It offered not only the knowledge and materials, but also the practical ways to practice and deliver what we learned through the platform."
"Thank you for this great course, it was a pleasure to be part of it. I wish that I could have been part of the first course as well. The data provided is more than useful and interesting, as was the feedbacks from a wide range of professionals. I will definitely join the next course and strongly recommend it to others."
"I think it is a very good opportunity to me to be introduced to different methods to design lighting schemes with a mindset that focused on the impacts for health, and I believe this experience and knowledge will be useful for my career."

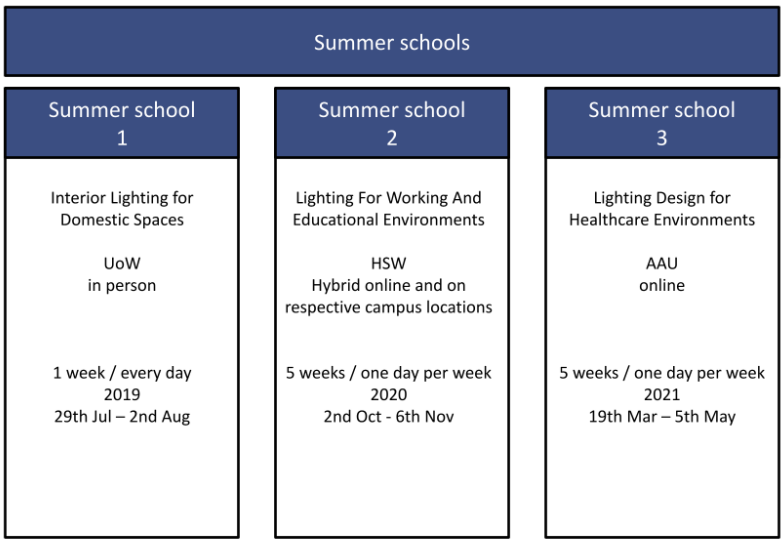

Figure 2. Summary of course content of the three Summer Schools

3.2. Multiplier events
Multiplier events (MEs) are required with all Erasmus+ projects in order to share the intellectual results of the project with a larger audience throughout the timeframe of the grant. Four MEs were conducted with a total of 300 external participants. The selection and involvement of participants depended on the host partner and the phase of the project. All MEs were advertised in social media and through partners' organizations, as well as by individual invitation. Arc lighting magazine (the foremost publication for lighting in architecture) was very supportive in disseminating the project through its newsletter as well.

3.2.1. Multiplayer Event #1 – L4H Public Workshop "Healthy Lighting for Working and Educational Environments" hosted by HSW

This event took place in March 2021, during the Light Symposium Wismar 2020/21 (LSW 2020/21) - a three-day online forum. This symposium delivers a state-of-the-art outline of how daylight and electric light affects the physical and mental health, efficiency, and performance of human beings. The L4H consortium partners used the opportunity to introduce the L4H project to a wider audience. The major target audience for this workshop was a mixture of: academia (educators and researchers), the lighting practice (designers), and the lighting industry (manufacturers). The workshop program included a Light4Health project presentation that discussed Summer School 1 and 2, and an introduction to Consortium partners. This was then followed by a panel discussion with 14 invited members of the Light4Health Team. The event was streamed online and it had an international reach, hosting 354 participants.

3.2.2. Multiplayer Event #2 – Light4Health Online Conference – Hosted by UOW

This event took place in May 2021, as an online conference aimed at students and academics, as well as employers. All L4H partners participated as speakers. The morning session gave an overview of the project so far (each of the three modules and summer schools), an introduction to factoring lighting in the design of buildings, with two case studies. In the afternoon session, speakers discussed lighting standards in domestic housing in the UK, the psychological influence of lighting, and there was also a talk about improving and installing lighting for astronauts for NASA. Each of these sessions provided an opportunity for feedback, discussion and Q&A. Over 150 people accepted invitations to attend and register; 22 external participants attended. The virtual format enabled participation from an international audience.

3.2.3. Multiplayer Event #3 – Launch of Light4Health eLearning Course "Health Research for Lighting Design" – Hosted by KTH

August 2021 – This course launch included a Light4Health project presentation with an introduction to consortium partners, a short summary of all the summer schools, and a summary of the previous multiplier events. This was followed by a panel discussion with six invited panelists who had reviewed the material for the online course. Feedback from reviewers was discussed. This was followed by questions from the audience. The event concluded with the live launch of the online course. Participants were also shown how they could register for the course, and were given a tour through the eLearning course on the Moodle platform. The event had an international reach due to being streamed online. In total 123 people attended the event (of which 108 were external participants). The major target audience for this workshop was a mixture of: academia (educators and researchers), the lighting practice (designers), and the lighting industry (luminaire manufacturers).

3.2.4. Multiplayer Event #4 – Online Conference "Transfer of Knowledge: Closing the Gap between Lighting Research and Lighting Design" – Hosted by ITMO

August 2021 – An online event to present the recently launched Light4Health educational eLearning course and eLearning platform. There was also a demonstration of relevant case studies and a discussion with the invited speakers about topics related to light and health. This event was streamed online and it had an international reach with 148 people registering for the online conference and 77 people attending, 70 of whom were external participants.

3.3. L4H eLearning course

The L4H eLearning course available on the Moodle platform, includes seven folders. The first is a course description, syllabus, and consortium information, the second folder contains material for teachers in the form of a Teachers' Guide and sample task assignments, and folders 3-7 contain five educational Modules with 28 video lectures and pdf slides, as well as reading reference lists and interactive self-assessment quizzes (Figure 3).

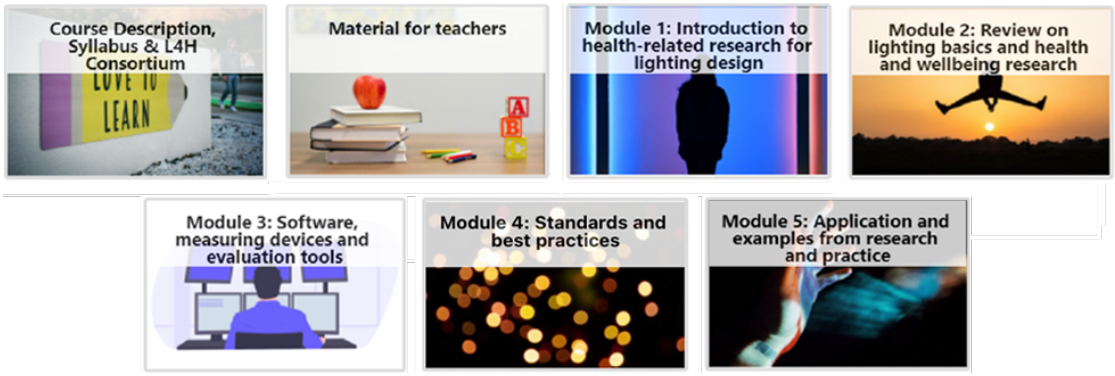

Figure 3. The L4H online course content as viewed on the Moodle eLearning platform

The development and organization of the content for the final L4H eLearning platform were based on content that was developed for the previous workshops, feedback and assessment from faculty and students, and the restructuring of the previous content. The course was designed to either function as both independent lectures and lessons, or as a complete course covering 1) a historical background about health- related research for lighting design, 2) an overview of lighting basics, and physiology related to light, 3) a range of tools for measuring, applying, and evaluating lighting metrics, 4) standards and best practices for lighting for health, and 5) their application in the form of case studies.
A more detailed description of the content of the five educational modules is provided in Table 1.

Table 1. Five Course Modules with detailed content

Module 1:	Introduction to health-related research for lighting design: Provides participants with a short history about light and health, and why we need to consider health as part of lighting design. The effects of light on the human body are also covered with an introduction to aspects of the physics of light and the physiology of vision.
Module 2:	Review on lighting basics and health and well-being research topics: Provides a review of lighting basics and lighting-related aspects of health. Included is daylight in architecture, the impact of daylight on health, and, in general, the neuroendocrine, neurobehavioral, and circadian effects of light on the human body. The psychology of light is also introduced; more specifically, how light is used as a visual trigger for psychological and behavioral impact. In addition, the topics of glare and flicker are discussed.
Module 3:	Software, measuring devices and evaluation tools: This module investigates software, measuring devices, and evaluation tools. Metrics are presented which can be used to assess the potential for the physiological impact of lighting, and different software and measurement tools are discussed. In addition, some assessment techniques are presented for the subjective impressions of a space. Finally, a tour is given of the Jefferson Lighting Research Lab.
Module 4:	Standards and best practices: Provides an overview of standards and good practices. Metrics for daylight evaluations are presented, and the “Manchester Recommendations” for healthy daytime, evening, and nighttime indoor light exposure are introduced. Moreover, design integrations are discussed. This involves employing measurements and design criteria for physiological impact and visual perception.

Module 5:	Application and examples from research and practice: Provides application examples and case studies from research and practice. In this context, several examples of light and health research are presented. This includes project examples from workspaces, and educational and healthcare environments. Specialty applications (e.g., space travel, users with autism), are also included, as are concepts of spectral modeling for light and health considerations, double dynamic lighting, biophilia, and information on therapeutic lighting applications.

4. Evaluating the L4H project content

An external quality assurance of the intellectual outputs of the project was important to its credibility. This involved three levels: 1) Qualitative evaluation by the L4H summer schools students; 2) Qualitative evaluation by the external reviewers/experts, and 3) Quantitative evaluation of the effectiveness of the online learning platform as an educational product. Formal validation and provision of the European Credit Transfer System (ECTS) was not possible due to the framework of a public open access platform, however each of the course modules was developed to be equivalent to 1 ECTS.

4.1. Pre-Launch evaluation by the L4H summer schools' students participants

Three innovative teaching workshops resulted in first-hand experiences and extensive feedback data to further improve the structure and navigability of the eLearning platform. The students participating in the workshops piloting the tools provided valuable feedback, including: that they learned many things that were unavailable elsewhere, they gained inspiration for their master thesis, they were introduced to new tools and software to evaluate lighting with an innovative approach that would be 'really meaningful in the professional field', and that working in a team with 'different cultural, educational background, and experience, had so much impact on the information I had and my way of thinking'.
Students had the opportunity to broaden their networks and get to know companies, academics and software as well as peers at partner universities. Exposure to scientific research to inform design was evaluated and shown to expand the skills and employability of students. Over 95% of survey respondents (21) reported that the experience of attending a L4H summer school session was a valuable experience overall, and 100% (22) said that the knowledge gained can be integrated into their studies and/or design practice. Other concrete impacts on L4H 'graduates' were increased confidence from completing the course and working in international teams.

4.2. Pre-Launch evaluation of the eLearning platform by the reviewers/experts

A draft of the final course content was reviewed and validated through 38 international expert reviewers including academics in the fields of lighting and health research, and professional experts in architecture and lighting design, who had access to the draft course materials for one month. The reviewers provided comments via a detailed online questionnaire. These comments were then used to make necessary improvements to the final course. Supportive feedback and valuable constructive criticism were provided on the pedagogical aspects and content of the draft; generally, there was a willingness to replicate the course. The collected feedback has been documented and it was used to make improvements to the course prior to the course launch, and logged to further inform possible updates of future content. 73% of the reviews by academics, indicated they were likely/highly likely to incorporate the materials in their teaching. Reviewers from professional lighting practices, architects and lighting manufacturers, expressed a strong interest in using the materials to inform their activities.
Academic reviewers included representatives from Parsons University (USA), Jönköping University (Sweden), Kongsberg University (Norway), Mount Sinai Medical Center (USA), Aarhus (Denmark), Build Research Institute (Denmark), Konstfack University (Sweden). Reviewers from professional lighting practices included: Global Designers Arup, The Lighting Practice (USA), Licht Kunst Licht (Germany), Liska (Iceland), Lightsphere (Switzerland) and Hoare Lea (UK).

Example comments:
"Students will clearly benefit from adding the topic of light and health to their lighting education."
"This course material could serve as a clear incentive to extend offerings and use this course as a resource, rather than having to develop material at each university."
"It provides engaging in-depth lectures on highly specific topics with field implications from the researchers engaged with the subject matter. This gives students unique insights into the topic in a medium that is very accessible."
"This gives a good foundation on light and health directly from the researchers involved. This could be a highly useful teaching tool, either as scaffold for a course or as supplement material to an array of lighting courses."

4.3. Post-Launch evaluation of the eLearning platform as an educational product

More than 221 users have registered to the L4H eLearning platform (https://course.light4health.net/) since the Final Course was launched at the end of August 2021. Users are mainly students, but there are also teachers and professionals. This number is in addition to the 117 users of the prototype during the summer school pilots.
The views of the L4H eLearning platform are more than 3500, including the views for the Modules, Teacher's Guide and project description. More specifically, Figure 4 shows the number of views per module for lectures, reference list and quizzes per module, while Figure 5 shows the percentage of views per continent. It is important to note that the high number of views for the self-assessment quiz, as well as the use of the online course all around the world.

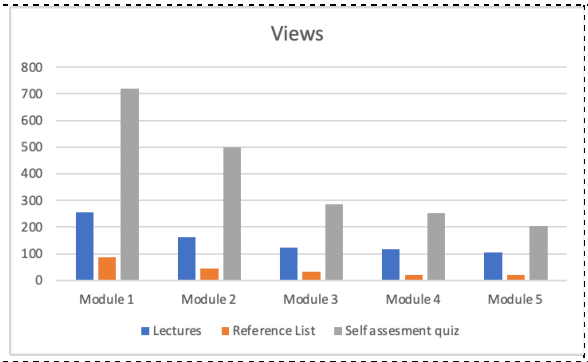

Figure 4. Number of views per module content

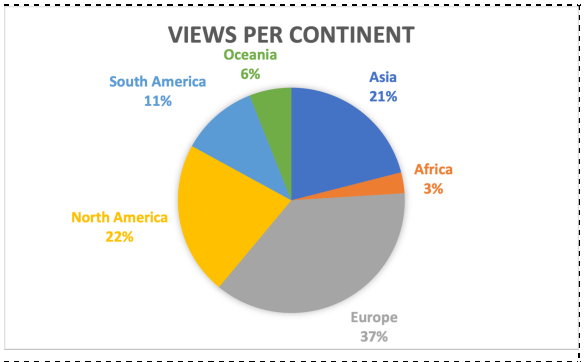

Figure 5. Percentage of views per continent

5. Findings and Potential Impact

Key innovative findings about this lighting design education project are grouped into the following categories below. They can inspire other researchers and teachers in lighting design.

5.1. Approach

- Research Driven Learning - students were shown how to access and interpret relevant and current peer reviewed papers from scientific research as a foundation for their designs.
- Interdisciplinary Learning - sharing education and research expertise from six organizations across multiple countries, universities, and departments that incorporates knowledge from Photobiology, Neuroscience research, Architecture, Psychology as well as Lighting Design, opened discussion to enable innovative solutions that reaches across diverse fields rather than silo-based learning.
- Team-Based Learning - teamwork plays an important role in the designing and construction of the built environment. The feedback from architects indicated having a base understanding of

Light4Health principles and tools, can facilitate team work and help ensure that lighting knowledge is not lost or compromised when engaging with the architect or those who commission buildings. Student feedback indicated the experience of working in teams to realize their final design project, demonstrated to them that design is rarely achieved, and that they need to develop a network in order to aid their future practice.

5.2. Application

- Applied Research - the application of scientific research directly to the design practice is not at all common in the area of architecture and lighting design. Students were shown how to go beyond studying the research, and to apply it to their own design processes.
- Adaptable to various educational platforms – the course is very flexible and versatile in that it can be taught in-person or remotely (or a combination of the two), or self-taught with assessment tools that can be used in both contexts by students or for ongoing training by professionals in the lighting industry.
- Accessible across professions - an innovative theme that emerged during the piloting and external review, was the real potential of the project to support and enhance teamwork between professionals beyond just lighting design (architects, engineers, surveyors, etc.) and those who commission construction or remodel works, highlighting where it is necessary to incorporate healthy lighting design. The online and modular nature of the course, clarity with which the topics are presented and the varying backgrounds and different perspectives of the partners that contributed to the course, makes it accessible as a resource to educate the wide range of practitioners and stakeholders that will contribute to the future development of healthy lighting.

5.3. Assessment

- Project Review – The curriculum provides a clear approach for both students and professionals, in how to apply research, as well as the methodology and tools that are needed to evaluate the impact of the final design. In addition to this, interest from the target groups (including academics, lighting practitioners/industry and students) was strong, as demonstrated by the 300 external participants across the five multiplier events (the target was 155), with a high proportion of international attendees. Finally, the goal for the official project website (https://www.light4health.net/) was 300 visits. At the time of writing this report, there have been more than 1000 views.
- Participant Review – Through extensive student and consortium partner feedback, not only was there continual refinement of the L4H project, but also room for further development and collaboration.
- External Review – The broad range of external reviewers confirmed the need and the value of the overall project and L4H platform for use across academic and professional fields. Manufacturers that attended the launch event considered it of utmost importance that they are invited into academia and that there is more discussion between lighting manufacturers, researchers, architects and designers so knowledge can drive innovation, and that this project has improved this dialogue.
- Platform Review – Since the launch in August 2021, data continues to be collected as per the overall use of the platform.

5. Future studies and course developments

We are aware that research on the effects of lighting on human health is a new and rapidly evolving field, and that subsequent investigation and its complexity demands further discussion to better understand it. This requires financial support to conduct independent research, the application of appropriate research tools and the development of new methodologies for measuring and predicting impact. In addition, how such tools are best implemented in the design processes is still a new field of investigation. We acknowledge that the L4H course content, while wide-ranging, does not encompass

the full extent of knowledge as health-related lighting design research continues to grow. Thus, the current course content is subject to refinements, updates, and revisions in future iterations. Further studies are needed so more knowledge can be integrated. Also, in addition to indoor lighting, outdoor lighting with increased global light pollution has been recently considered a potential origin of certain chronic diseases in human beings. We hope this project inspires further investigation by the health research community and that this also involves a close collaboration with the design community to inform health-conscious design processes and its implementation in the built environment.

6. Conclusion – Enacting change

This work highlights the timely recognition of the significance to health and well-being of indoor environments where people spend most of their time. The emphasis on the importance of quality lighting in the built environment indicates a shift toward a more holistic approach.

The Light4Health project's impact includes many aspects – both within the EU and internationally, while also providing benefits to society and the economy at a local, regional and national level. Through intensive cross-border and cross-disciplinary cooperation, the project has triggered collaborations and produced results that are already in use at the university level across many countries, and are likely to develop further. The project will help to prepare graduates for the lighting industry and related employers in Europe and around the world, thus contributing to more research-driven, knowledge-based, competitive economies.

We have estimated that approximately 10,000 people were reached directly or indirectly by the L4H project activities. These include: (1) those involved in developing the course content - either through the contribution of their expertise or review; this group encompasses students and graduates of partner universities, lighting professionals, academics, architects, and lighting manufacturers; (2) External experts and stakeholders; (3) Summer School participants and those who accessed the material contained in the first three modules tracked as through the eLearning platform and the users of the final L4H course measured since its launch at the end of August 2021 (4) External participants in the Multiplier Events; (5) those involved through social media, the project website, recruitment for summer schools, publications such as press releases and articles, television and radio broadcasts, and other forms of promotion and dissemination of the project.

With this project participants and consortium members have narrowed the gap between research and the practice/application of lighting, translating research from complex scientific jargon into tools for designers to use. Through the use of the L4H education eLearning platform, we hope the lighting community will acknowledge the importance of health and wellbeing as a major principle in engineering and the design of light and lighting systems.

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