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Light pollution – an interesting context for teaching and learning optics

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Light pollution – an interesting context for teaching and learning optics

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Abstract. Physics as a school subject is in general very unpopular. This fact is especially true for the situation in Austria. PISA results show that motivation, interest and self-efficacy of Austrian highschool students are significantly lower than the OECD average. In addition, a significant gender-gap in disadvantage for girls was shown. In general, one reason for low interest which was identified by previous research is that physics instruction is frequently decontextualized and students can hardly see any relevance of understanding physics for their lives. On the contrary, science and technology play a crucial and increasingly important role in our lives and in our globalized society. At the same time, edutainment focusing on science topics is booming. Interest studies like the ROSE-study may give reasons for this discrepancy: the choice of contexts does often not meet students' interests. This contribution reports the development of a context-oriented learning environment on light pollution to stimulate learning processes and at the same time interest in introductory optics.

1. Introduction and Motivation

In our everyday life we are confronted with new technologies and devices that make our lives easier and more comfortable. On the other hand, our current technological lifestyle has also negative side effects. Not all of those side-effects may be obvious to everybody at first glance. Next to a basic understanding of how things work, it is one major educational goal of science and physics teaching to make students aware of such risks. In addition to knowing about negative effects on society and health caused by our technological lifestyle, science education should provide students with competences to make evidence based decisions for their everyday life. However, the results of PISA and other studies show that in Austria, science instruction is still very traditional, fact-oriented, non-adaptive and teacher-centred, avoiding approaches which train students' competences in interpreting data and evidences scientifically and drawing appropriate scientific conclusions [1–4]. So, it is not a big surprise that Austrian students do not perform well in these categories. In addition, their motivation to learn science as a future resource for their everyday life is very low compared to the OECD average. And in PISA 2015 again, a big gender-gap was diagnosed [4].

Taking these circumstances into consideration, one working field of our research group is the design of research-based teaching and learning environments that follow constructivist ideas and address students' interests and needs by using a context-oriented approach. In this contribution we focus on the topic of introductory optics and report the development and testing of a teaching and learning unit for highschool students.

2. Theoretical Background: Interest and scientific literacy as general aims of physics teaching

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In the following section context orientation and the use of socioscientific issues as an option for interest generating science instruction is discussed. In addition, this approach is set into relation to scientific literacy as the major educational goal of science instruction.

2.1. Interest, Motivation and Contexts

It is out of question that most aspects of our life are influence by scientific knowledge and its technical application. Even individual success and career opportunities are related to scientific literacy skills nowadays. From international comparative studies like PISA and TIMSS we know perfectly well that interest and motivation in science is generally not too high in many European countries and that girls show frequently even less interest than boys. For Austria this situation is even worse. According to PISA 2015 the instrumental motivation for science is amongst the lowest in Europe as well as the enjoyment of science. In addition, there is a highly significant gender gap in disadvantage for Austrian girls. [1], [4]. When taking PISA results into account, it is also important to note that students' interests and affections concerning different science subjects are not differentiated, but popularity, interest and motivation for different science subjects differ significantly among students. For the German speaking countries, there are for example numerous evidences that physics is the most disliked and uninteresting subject within the science subjects [5]. So, we can infer that the situation for the school subject physics is even worse.

Studies like PISA diagnose deficits in certain areas like motivation, interest, enjoyment or self-efficacy in science, however, a detailed analysis remains open. Research on students' interest in science (ROSE, IPN) [5–7] on the other hand, hints at certain reasons and investigates special fields of interest. So, there is a lot of evidence showing that students' needs and interests are frequently not in line with topics and contexts chosen for conventional instruction. The Relevance of Science Education (ROSE) study [7], which was conducted in about 40 countries, investigated teenagers' interest in different science contents and contexts. The findings show that "the ***Context*** is a key to understand the expressed Interest" [7].

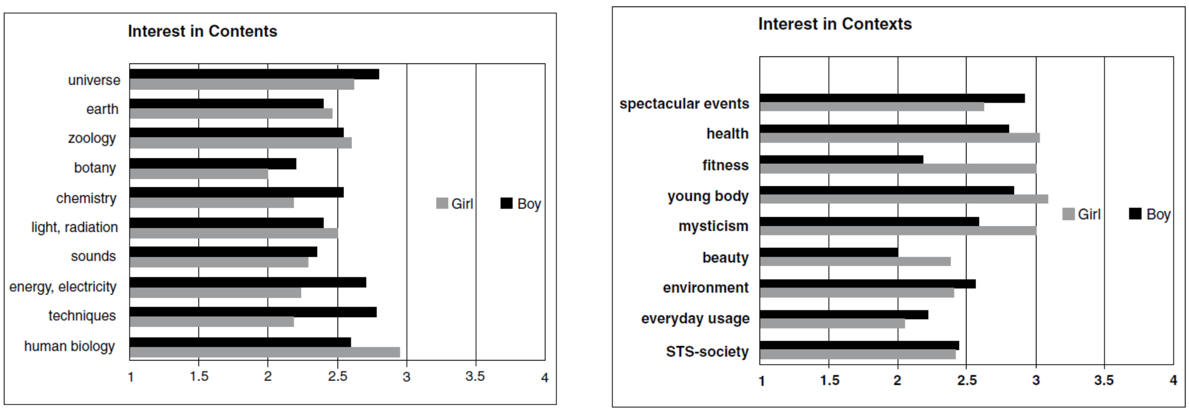

Figure 2. Interest of boys and girls in science subjects. x-axis: four-point Likert scale (1 = not interesting, 4 = very interesting).

Figure 3. Interest of boys and girls in natural science contexts. X-axis: four-point Likert scale (1 = not interesting, 4 = very interesting).

Figure 1. Results of the ROSE-study in Austria and Germany: interesting content and contexts [6].

The results of ROSE are in good accordance with the IPN interest study which was conducted in Germany and seems to be representative for the German speaking area [5]. There too, as in several other studies, one finding is that conventional instruction does frequently not meet students' fields of interest. Conventional physics classes do typically not integrate contexts like social, environmental or health issues which are of high and equal interest for male and female highschool students.

Context-oriented instruction is seen as one way for improving this situation. "Context-based approaches are approaches adopted in science teaching where contexts and applications of science are used as the starting point for the development of scientific ideas. This contrasts with more traditional approaches that cover scientific ideas first, before looking at applications." [8]. A review of research literature shows that context-based approaches are very likely to "result in improvement in attitudes to science [while] the understanding of scientific ideas developed is comparable to that of conventional approaches. The approaches also result in more positive attitudes to science in both girls and boys and reduce the gender differences in attitudes." [8]

2.2. General aims of physics instruction at highschool level – scientific literacy

During the last years a paradigm-shift has taken place in science education, from input-orientation to output-orientation and from cumulating scientific facts to developing interrelated competencies. A general aim of science and physics instruction is "the application of science knowledge and skills in real-life situations, as opposed to testing particular curricular components." [9]. This approach can be summarized under the umbrella term of scientific literacy. There is no general and single definition of scientific literacy, one frequently used was coined by Bybee [10, 11] and is the basis for PISA and its framework: "Scientific literacy is defined as the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity." [9]. This definition bases scientific literacy on three dimensions, namely (1) scientific knowledge or concepts, (2) scientific processes and (3) the situations or context in which the knowledge and processes are assessed.

The orientation towards scientific literacy as a general goal of science education asks for instructional approaches complementing traditional settings which are frequently aiming at the transmission of "pure" scientific facts. Context-orientation as mentioned above is one way of engaging students in real-life situations and supporting the development of scientific literacy. Socioscientific issues – social dilemmas with conceptual ties to science [12] – represent a certain category of contexts. Researchers as well as practitioners see them as an opportunity to meet students' interest and at the same time to initiate the development of scientific literacy, as they combine the development of different competencies: "Negotiating socioscientific issues involves understanding the content of an issue, processing information regarding the issue, attending to moral and ethical ramifications of the issue, and adopting a position on the issue." [12]

3. The development of a teaching and learning environment on light pollution

The general goal was to develop a teaching-learning environment for year 8 students that fosters a basic understanding of core concepts of introductory optics. One of our design principles was to use a context-based approach. The teaching and learning environment should be based on a context that is equally interesting for female and male students. In addition, we wanted not only to promote content knowledge, but also the competency to apply this knowledge in real-life situations and train decision-making strategies. Taking all our considerations into account, the approach using of socioscientific issues fitted our needs well.

The topic of light pollution can server as such a socioscientific issue which addresses students' interest and supports learning processes in optics. Light pollution, which can be defined as the presence of anthropogenic light in the night environment, is a phenomenon of our modern society. In general, light has a very positive connotation as it enables modern society to be active even after sunset. Negative side-effects of the massive illumination of our natural surroundings and thus of the reduction of night environments have not entered public perception so far. There is also a lack of research on the phenomenon of light pollution. All in all, light pollution turns out as perfect content to support our intention of developing a teaching and learning environment that trains the application of content knowledge in real-life situations and decision-making strategies.

3.1. Design Based Research (DBR) and Educational Reconstruction (ER)

Design Based Research (DBR) integrates two endeavours – development and research – in the process of designing artefacts (teaching materials, learning strategies, curricula, etc.) for school practice. The starting point of DBR is usually a concrete problem taken from educational practice, like in our case Austrian students' average cognitive performance and low motivational and affective results in PISA. DBR seeks to develop specific, innovative and practicable solutions for school practice, which are research based on the one hand and which generate at the same time theories on sub-domain specific learning processes. DBR is a cyclic and iterative process with the overall aim to learn "how, when, and why educational innovations work in practice" [13].

As theoretical framework model for the development of a first version of our teaching and learning environment, we used the model of educational reconstruction. In this constructivist approach three components are interrelated and connected: 1) "clarification and analysis of subject matter", 2) "students' and teachers' perspectives regarding the chosen subject" and 3) "design and evaluation of learning environments" [14] (cf. figure 2).

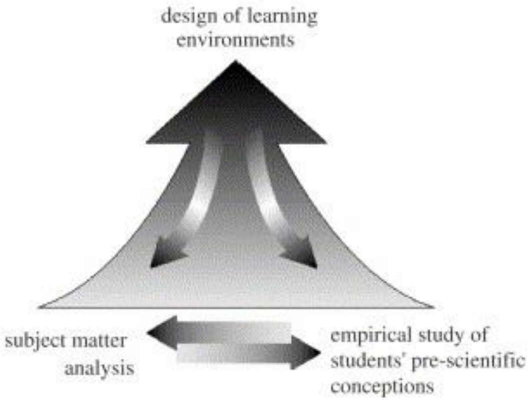

Figure 2. The model of educational reconstruction, based on [15]

In a first step light pollution was analysed as scientific content. Light pollution can be defined as "excessive, misdirected, or obtrusive, artificial (usually outdoor) light." [16]. As such, there are several key concepts of introductory optics which can be developed within this context. The most important are: Propagation of light, light and shadow, light and vision (sender-emission-receiver model), interaction of light and matter (reflection and scattering) as well as light and colour (spectral nature of white light). Besides these topics, light pollution provides a number of aspects going beyond mere physics subject matter and involves social, environmental and health issues: "Too much light pollution has consequences: it washes out starlight in the night sky, interferes with astronomical research, disrupts ecosystems, has adverse health effects and wastes energy." In addition, it is a relatively new research field. Despite the increasing interest among scientists in fields such as ecology, astronomy, health care and land-use planning, light pollution lacks a current quantification of its magnitude on a global scale" [17]. This is usually an interest generating momentum for students as they get the feeling of involvement in current research.

The model of educational reconstruction states that the design of successful learning environments needs to merge the subject matter point of view on a certain topic with related student perspectives (including preconceptions and interests). So, in parallel to the clarification of the subject matter, special fields of interests and students' conceptions need to be identified. As far as interest is concerned, the ROSE study [6] provides a good choice of topics which are of high interest for female and male students. As figure 1 shows, light/radiation are among the most interesting contents and health and environment among the most interesting contexts. Although, there are many more cross-links to the topic of light pollution, we restricted our focus to those contexts and contents mentioned above.

As far as students' conceptions are concerned, there is quite a solid knowledge about students' inadequate ideas in optics, however, specific conceptions on the topic of light pollution could not be identified. So, an additional aim of our project was to explore students' ideas in this field. The explorative results were gained in a pretesting phase to this intervention. These results gave a quite solid first impression about existing students' conceptions [18], which were validated and expanded in subsequent interview studies of our group [19]. In general, students associate positive feelings with light, like: *beautiful, nice, bright*. For most of them light creates an atmosphere of cosiness and security. The phenomenon of light pollution is frequently unfamiliar, and the term is associated – in parallel to the construct of air pollution – with a deterioration of the quality of light. Most students are not aware of the existence of light pollution in their everyday life or their living environment and they categorize light pollution as a problem exclusive to big cities.

In addition to specific conceptions about light pollution, there are several learning difficulties which are known from research findings in optics [21, 22]. The most prominent can be summarized as: low acceptance of the spectral nature of white light, difficulties in interpreting spectral distribution diagrams (radiation curves) of white light sources and problematic conceptions about scattering of light.

3.2. Design Principles
The major design principles guiding the development of our teaching and learning environment for light pollution were a constructivist approach to learning in general as well as an emphasis on a context-oriented structure of the learning path. So, the teaching and learning environment was not to start with input on or construction of content knowledge, but had to provide the engage-phase to grasp the phenomenological aspect of light pollution and problems connected to its existence. Only after this cognitive activation and the generation of problem awareness, students are supported to acquire relevant scientific knowledge to identify questions and to draw evidence-based conclusions. For structuring the learning paths in such a way, the 5E-Model (engage, explore, explain, elaborate, evaluate) by Bybee [23] was used.

This structure on the level of the learning path mirrors the structure Sadler et al. suggest for handling socioscientific issues: "Negotiating socioscientific issues involves understanding the content of an issue, processing information regarding the issue, attending to moral and ethical ramifications of the issue, and adopting a position on the issue." [12]

According to PISA, Austrian students lack inquiry skills and science instruction is very teacher-centred and rarely involves students in inquiry activities [4]. So, we cannot take for granted that students are familiar with inquiry based learning, especially not with open inquiry settings. Therefore, we decided to suggest guided inquiry scenarios for this teaching and learning environment, which can however easily be adopted as more open formats.

3.3. The content structure of the teaching and learning environment
The teaching and learning environment on light pollution is designed for three to four school lessons.

The **engage** phase (see figure 3) of the teaching and learning environment starts with a picture stimulus, where students have to compare two different pictures of the night sky, which show the same part of the night sky with different amounts of light pollution. Only after the students have found out about that, they have to **explore** the mechanisms causing this effect. Propagation of light, reflection and (atomic) scattering are the scientific key-concepts behind light pollution, students have to understand. After being familiar with the idea of light pollution on a general level, students have to identify different sources of light pollution and **explain** how and why they contribute to light pollution.

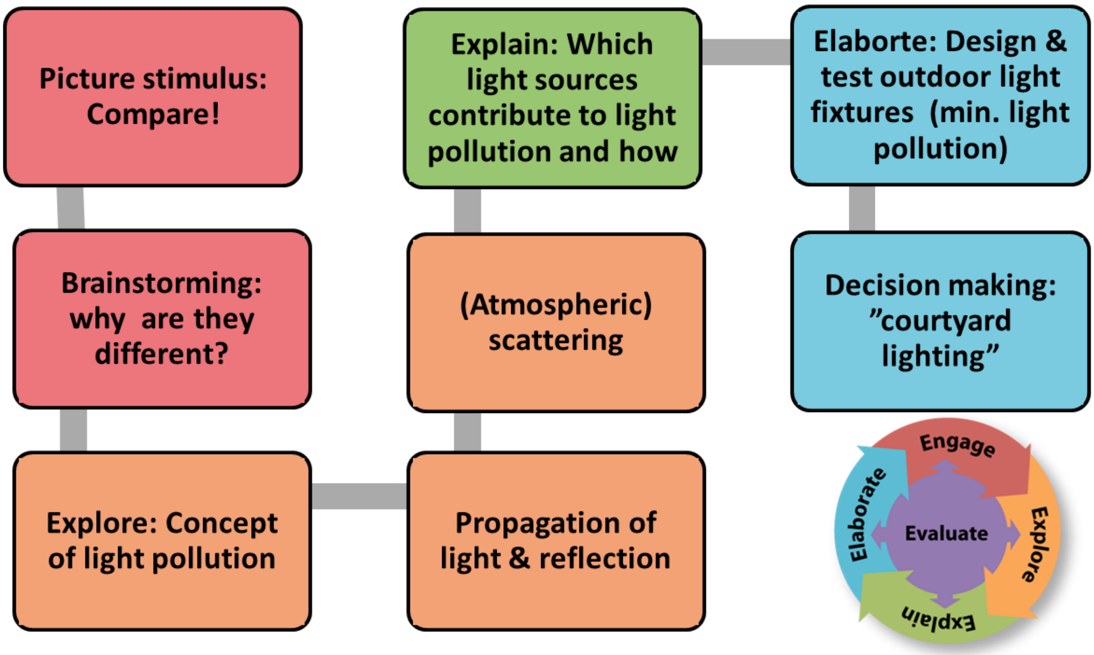

Figure 3. Structure of the teaching and learning environment inspired by the 5E-Model. The four phases Engage, Explore, Explain and Elaborate are indicated by colour codes. Evaluate is an integrative part of all phases and therefore not indicated.

The **elaborate** stage is divided in two different activities. The first one uses an inquiry based approach for a practical lab activity. The second activity focuses on decision-making processes, which are one feature of socioscientific issues.

In the lab activity, students work on the task to design and test an outdoor light fixture that produces minimal light pollution. Their inquiry is structured into 4 steps:

- Collect parameters / limiting factors for the light fixture concerning light pollution.
- Draw a sketch.
- Build a model using cardboard and sticky tape.
- Measure the illuminated area using a mobile app. Write the results on the blackboard.

In a final reflexion and discussion phase, the measurements documented on the blackboard are compared and discussed in class.

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Figure 4. Picture a) Provided light source and the students’ measurements on the whiteboard. Picture b) Shows a group of students testing their light fixture.

For the decision-making activity, the students work on two different task. One is shown in figure 5:

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Figure 5. Decision-making task "courtyard lighting".

The students again work in teams. Figure 6 shows an extract of a table that can be integrated in the task to support the students. Depending on the class and the students' abilities such a table can be given to all teams or just to those team who need special support.

	bulb	LED cold white	LED warm white	low-pressure sodium vapour lamp
efficiency				
colour rendering				
spectral distribution				

Figure 6. Table guiding the decision-making task "courtyard lighting".

After each group has finished the task, new groups are formed, consisting of members of different previous groups. In this constellation, the decisions of the original groups are presented and discussed.

4. Research on the teaching and learning environment on light pollution

The research design reflects the goals for this learning environment, namely to trigger motivation, to train decision-making, to gain content knowledge about some subtopics of optics and to raise awareness.

4.1. Research Design

The first part of the teaching and learning environment was tested with 114 students (52 male, 62 female) in six year 8 classes. The students lived in rural areas or in small cities, their schools were also situated in small cities.

Figure 7 shows the structure of the classical pre-post design. Before the intervention, a questionnaire was administered which consisted of open questions on students' familiarity with light pollution as well as on their general attitude about environment protection. In addition, the pre-questionnaire consisted of test-items on the conceptual understanding of relevant subtopics of optics. These test items were taken from a two-tired conceptual test on optics, which had been developed in accordance the Austrian year 8 curriculum for physics [20]. The six two-tired test items used cover the following concepts: propagation of light, process of vision (sender-emission-receiver model), reflexion and scattering of light.

After the intervention the administered questionnaire consisted of five parts: open questions on students' familiarity with light pollution and about their knowledge about the formation of light pollution. In addition to their general attitude about environment protection, students were asked about their attitude about light pollution as environmental issue. The test-items on the conceptual understanding of relevant subtopics of optics of the pre-test were repeated. Finally, students' interest concerning the teaching and learning environment was tested.

The items of the optics test were statistically analysed, while the open ended questions were analysed with quantitative content analysis.

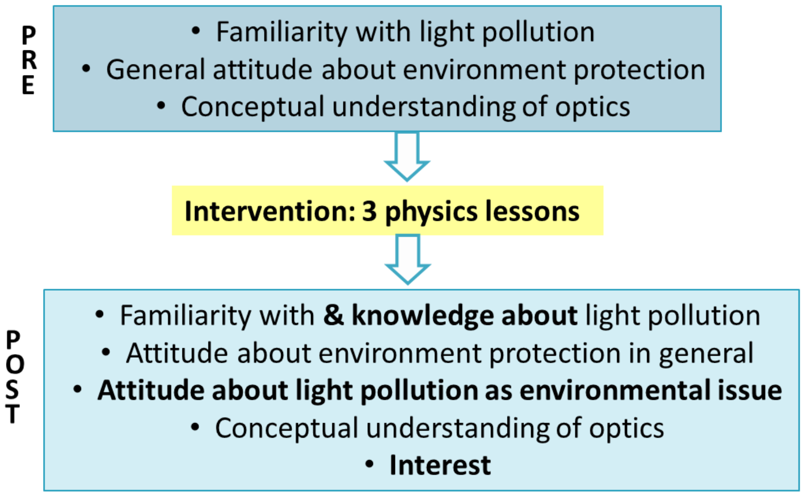

Figure 7. Research Design

4.2. Findings

Before the intervention, the majority of students were not familiar with the phenomenon of light pollution, neither could they give an appropriate explanation. This situation has changed significantly after the intervention (see figure 8). Only one participant did not give any answer. All the other students gave an appropriate answer and demonstrated familiarity with the phenomenon of light pollution. They were also able to name the most important sources of light pollution.

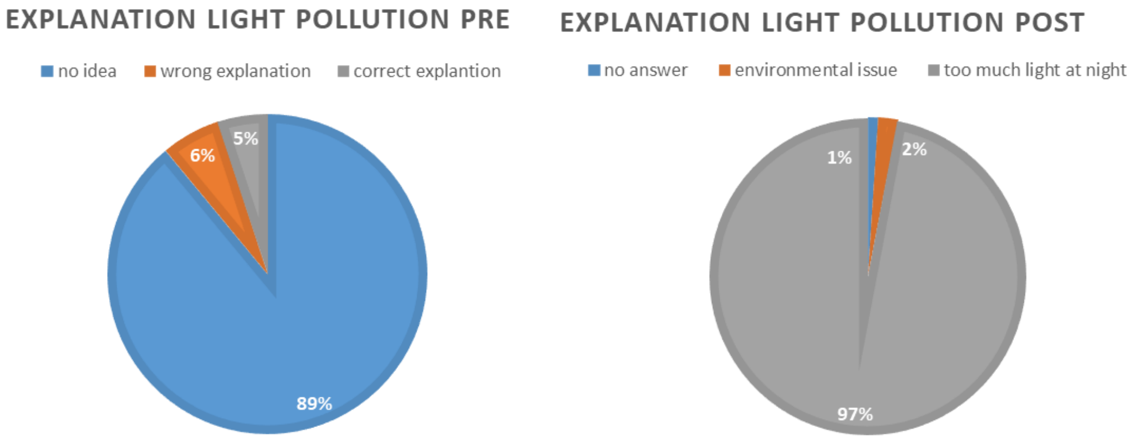

Figure 8. Knowledge about the phenomenon light pollution

The post questionnaire shows that all students have a positive attitude towards the teaching and learning environment on light pollution. This is a very exceptional result, as it is quite unusual, that not any dislike is expressed. Reasons for the high interest in the teaching and learning environment are based on the fact that students can draw relations to real life situations and the learning environment represents an application of their content knowledge in optics. Boys and girls equally see potential connections to their own lives as figure 9 shows.

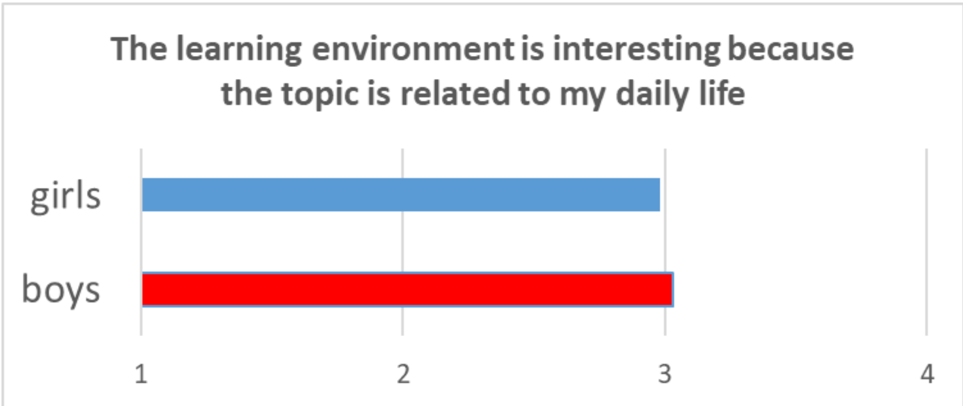

Figure 9. Interest generating factors in the teaching and learning environment: connection to everyday life on a four-point Likert scale (1=total disagreement; 4=full agreement)

Further analysis shows that the teaching and learning environment is not only of high interest for the participants, but also that the girls show higher interest values. For the participants, light pollution seems to be a topic that is of higher interest than most classical topics of physics classes. In additional, girls find it even slightly more interesting than boys do. These results go along with the initial assumptions we have drawn from research on interest like the ROSE study.

While light pollution was not regarded as environmental issue before the intervention, this question was answered in a quite differentiated and more reflected way afterwards: Students mentioned negative effects of light pollution on insects (63%), migrant birds (44%), nocturnal animals (26%), human health (52%) and plants (11%). The results of the post-questionnaire indicate that three quarters of the participants are willing to promote ecological lightening in future. This aspect is also supported more by girls than by boys (63% girls, 37% boys). As strategies for doing so, they mention to avoid light at night where possible, to raise awareness about this issue among their friends and families or to use curtains and blinds to block light during night. However, about 20% of the students do not think that light pollution is an environmental topic that will play any future role in their life. The majority of them mentions as reason that they live in a small village where light pollution is not an issue at all. Other reasons mentioned are that there are other, more important environmental issues like climate change or that a single person can not change anything.

As far as the learning output on a content level is concerned, a significant knowledge gain can be diagnosed in the subtopics with one exception, namely reflection. In the subtopic of reflection, the knowledge gain was positive, however, it did not significantly differ.

When the pre- and post-test results are compared, we note a difference in the pre-knowledge level of boys and girls. The pre-knowledge of boys is higher than that of the girls. This gender-gap is cancelled out in most sub-scales of the post-test. The knowledge gain of girls is significantly higher in the scales on scattering (boys: 3%; girls: 13%) and propagation of light (boys: 5%; girls 16%). In the subscale on the sender-emission-receiver model the gain of the girls is higher than that of the boys, but only slightly (boys: 13%; girls 18%).

5. Discussion and conclusion

Physics is in Austria, as in many other countries too, one of the least popular school subject. PISA results indicate that Austrian students do not show a lot of personal interest in science, nor are they very motivated for science, at least in a school contexts. What is even more worrying is that there is a big gender-gap in disadvantage for the girls. Interest studies show possible reasons for this situation, namely that instruction is frequently decontextualized, or uses contexts that are not of equal interest for boys and girls. On the other hand, science education in Austria is very traditional and fact oriented. The majority of students lack competences like interpreting data and evidences scientifically and drawing appropriate scientific conclusions. Most Austrian teachers are however very cautious concerning inquiry based learning approaches and / or lessons that focus on decision-making processes, although both are part of the Austrian science standards. The main motive to avoid such approaches seems to be the argument that such approaches may have negative effects on the acquisition of content knowledge.

So, the idea behind our project was to develop a teaching and learning environment for introductory optics which is structured in a context-oriented way. As context we chose light pollution, since we assumed - based on the results of interests studies - that this context might be of equally high interest for boys and girls. In addition, we integrated an inquiry based approach and elements training evidence based decision making processes. The aim was to show that learning environments that are adaptive to students’ interests do not necessarily lead to low content knowledge gains and are able to motivate students for physics.

As the comparison of the pre-post-test results on students’ conceptions show, the knowledge-gain is more than satisfactory. What is even more, the girls were able to cancel out their lower pre-knowledge. The results of the questionnaire also indicate that the learning environment was able to trigger interest, especially due to its relevance for students’ life and the approach that allows students to apply knowledge. So, our assumption that light pollution might be an interest generating content proved to be correct, at least for our sample. For our case, it turns also out that context-orientation does not necessarily influence content learning negatively.

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