Revision of an Optical Engineering Lecture Based on Students' Evaluation of University Teaching

Thorsten Beuth, Svetlana Danilova, Harsha Umesh Babu, Siegwart Bogatscher, Leilei Shinohara, and Nico Heussner

***Abstract*—This article describes the revision of a lecture in optical engineering based on an evaluation of university teaching by students. Although this evaluation method is widely accepted and investigated, only few practically oriented reports on the deduction of teaching improvements from the evaluation's results on lectures are available. Our approach is the analysis of evaluation results by applying the principles of the explorative factor analysis (EFA). The changes that were derived from this analysis were mainly focused on a revision of the course structure and its presentation style.Finally, the impact of the modifications was measured by the evaluation of the lecture after the completed revision. The later evaluation showed improvements in all intended areas of interests illustrating the benefit of thorough revisions for the quality of teaching.**

***Index Terms*—Students' evaluation of university teaching, engineering education, higher education, optical engineering.**

I. Introduction

Students' evaluations of university teaching (SET) is a widely used tool to improve teaching quality in higher education [1], [2], especially in Germany [3]. To complement the rather theoretical point of view of the majority of studies [4], [5], a practical insight into the efforts of our revision process for one of our lectures is given in this paper. It was observed that in the last few years, the ratings of the Optical Engineering (OE) lecture in the international graduate program had dipped. After carefully analyzing the ratings, going through comments and acquiring feedback through informal conversations with students, it has been decided to overhaul the course. This paper captures the analysis of the student evaluation supplied by a mandatory information system of the university, the measures and a subsequentanalysis of the improved ratings.

In Section II, the OE lecture's setting in the curriculum andthe target audience are introduced. Section III explains of the underlying evaluation process. The analysis of the initial evaluation results are presented in Section IV. A plan, which was elaborated to restructurethe course and the measures to evaluate the changesare shown in Section V. This section also contains an analysis of the evaluation after the revision. A look at the key indicators and their interdependence is given which supports the principles of the explorative factor analysis (EFA) [6]-[8]. This is used to reflectively judge our ratings.

The analysis and position on the student evaluation method in general are presented, looking at dependencies of key indicators on subject, target audience and other factors. With this understanding, the outcomes of OE evaluation are reflected and changes ofthe student evaluation method are suggested. The results of this work are summarized in Section VI.

II. Background on the OE Lecture and Its Evaluation

OE is a first year graduate course offered to master students from the graduate school of Karlsruhe School of Optics and Photonics (KSOP) as well as students from the Electrical and Information Technology (ETIT) faculty. In addition there are always few students from computer science and mechanical engineering who attend the course to broaden their scope.

Since OE is an engineering course, the focus lies on applications of optical phenomena, techniques and their analysis. Starting with a recap of basic optical phenomena, simple optical systems are introduced like microscope, telescope or the camera. The evolution of these systems is shown as well. The lecture continues with detailed analysis of the human eye, its aberrations, the design of intraocular lenses and their analysis. Acquainting the audience with examples of optical systems and providing an understanding of their basic mechanisms, the lecture expands into techniques involved in design and analysis of such systems. Also the background theory (e.g. Fourier analysis, field theory etc.) needed for such study is elaborated wherever possible and references are provided when the material is trivial or out of purview. More advanced optical systems are covered in the form of LIDAR, pico-projectors using micro-mirrors and laser Doppler velocimeters.

At the end of the course, students gain a strong foundation in different applications of optics. The course provides insight into understanding requirements involved in optical solutions and design of optical components and systems.

An additional tutorial is offered along with this course in which students get further insight by solving some simple problems which are all pen and paper based. To get a more practical understanding, students are encouraged to take part in an Optical Design Laboratory (ODL) either in the same semester or the following. Students learn to design and

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T. Beuth, S. Danilova, H. Umesh Babu, S. Bogatscher, and L. Shinohara are with the Institute for Information Processing Technologies (ITIV) at the Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany (e-mail: thorsten.beuth@kit.edu, svetlana.danilova@kit.edu, harsha.umeshbabu@kit.edu, leilei.shinohara@kit.edu).

N. Heussner is with the Forschungszentrum Informatik (FZI), Karlsruhe, Germany (e-mail: heussner@fzi.de).

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evaluate optical components and simple systems with Zemax (widely-used optical ray tracing software) in ODL. During the period under consideration the quality index ratings for OE tutorials was 94.4 out of 100 (winter term 2011/12) and 92 out of 100 for ODL (winter term 2011/12). These evaluation results are quoted for the sake of completeness and to emphasize that there is no necessity to restructure the tutorials and ODL.

Both are courses but influenced significantly by OE. Therefore, in the course of restructuring OE, care has to be taken that these do not suffer.

III. Evaluation Process

At the Karlsruhe Institute of Technology (KIT) it is mandatory that every lecture is evaluated by students [9]. Students can rate a wide range of indicators (up to 40) affecting classroom teaching like the usage of black boards, clarity of the speaker, script quality and learning success among others, with an integer value from 1 (very good) to 5 (very bad). For each indicator an average (vI) is calculated. The university supports the lecturer with the averaged value of each indicator and its standard derivation but just a graphical depiction of the raw data.Therefore, it is hard to inspect dependencies from year to year, e.g. by t-test statistics.

Five key indicators are taken as a base to calculate a teaching quality index called "Lehrqualitätsindex" (LQI). If the indicator's average is between 1.0 and 2.5, its quality value (sLQI) is judged as 100. Between 2.5 and 3.5 there is a linear dropdown following the formula $sLQI = (3.5 - vI) \times 100$. If the average is between 3.5 and 5, its sLQI is 0. Five sLQIs are weighted with a number between 0 and 1 and then summed up for the calculation of the overall lecture's LQI. The LQI is usually calculated for lectures by the key indicators overall impression, work load, course structure, (perceived) dedication of the lecturer and his responsiveness (these indicators are applicable for our evaluation as well). It is flexible in a way that indicators used in computation of the quality index can be changed upon request to more fitting items. The calculation process is displayed in Fig. 1.

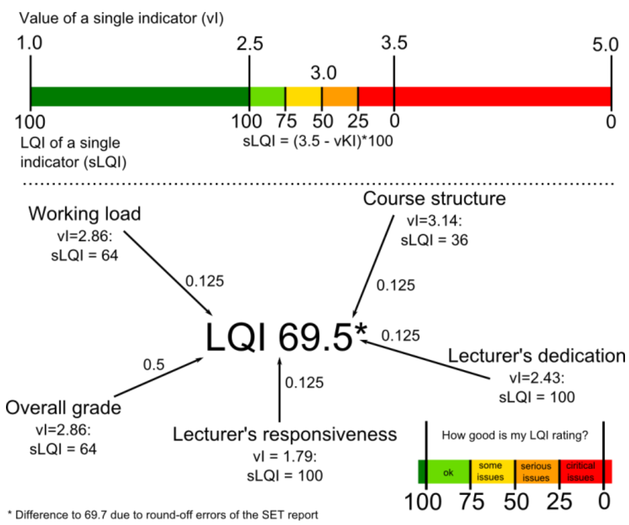

Fig. 1. Example calculation of the LQI of OE lecture in winter 2011/12.

The LQI is taken as a raw measuring tool for the departmental advisory boards to identify issues in teaching quality. As a rule of thumb, the LQI signals a necessity for improvement when it drops below 75 points. A value below 50 points indicates serious issues that need to be addressed.

In the winter term of 2011/12 the course "Optical Engineering" (OE) obtained 69.7 points which indicated some issues to be fixed. Therefore it has been decided to revise the course based on the information given by the SET. The process of revision with the help of such SETs schemes and the principles of the scholarship of teaching and learning (SOTL) [10], [11] are the key points of this paper. To our knowledge this is the first documented in-depth review of a lecture at the KIT based on the here documented evaluation information system.

IV. Analyzing the Current State

The first step of the revision has been an analysis of the current state of the lecture. Therefore, we have had to ask who is our audience and what skills can we expect from them. Furthermore there has been the question of what the lecture's strengths and weaknesses are. By understanding our weaknesses, we can deviate our goals.

A. The Audience

It is accepted that every country and culture has their own influence on teaching and study methods [12], [13]. In the last few years, the rising influx of international students has caused a change in audience demographics. Satisfying the audience with wide ranging background in terms of study methodologies is a challenge.

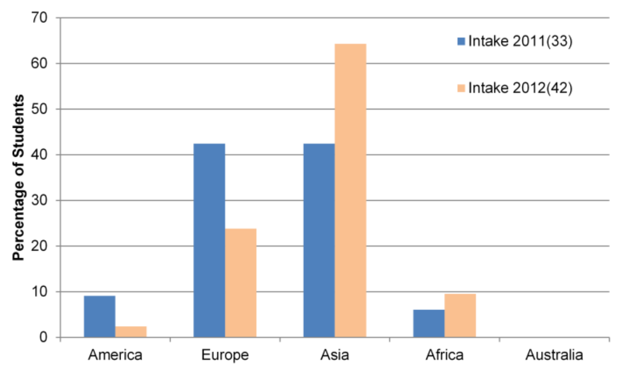

Fig. 2. Origins of the KSOP students by continent. The amount of intakes in 2011 has been 33, in 2012 42.

The evaluation's data has been taken as a starting point for improvement. First our target audience was determined from the winter term 2011/2012. Around 70% were postgraduate students of the Karlsruhe School of Optics and Photonics, 30% of the students were postgraduates in Electrical and Information Technology studies. KSOP students came from a very diverse and broad spectrum of different scientific disciplines from four continents (see Fig. 2). They have had all been excellent students in their former universities but standards vary significantly. For KSOP students OE is a mandatory course in the first semester of their postgraduate studies.

ETIT students were mostly German. Since the participation in the evaluation is voluntary for the students, not all students were in the evaluation pool. Also it was known that there were some ETIT exchange and undergraduate students among audience from our informal conversations with students. For ETIT students OE is an elective course which they can choose in their late undergraduate or in their postgraduate studies.

Finally, to set the lowest common denominator for the prerequisites, our audience has been expected to be at least a 3rd year undergraduate student with an understanding of advanced mathematics – in the form of linear algebra, integral calculus, Fourier transform, etc., and comfortable with technical and scientific English. The students' previous knowledge should consist of all the basic scientific optical effects which are usually explained in the physics lectures in the first year of their study. Nevertheless it is crucial to have a short recap of the basic knowledge in one or two sessions to set a base for all students since varying standards are expected.

B. SET Analysis

In this section we present the SET analysis which has been the base for the identification of the lecture's strengths and weaknesses. As a closer look was taken to the ratings related to script, quality of slides, board writing and structure, it revealed a general disaffection with all of the indicators receiving an unsatisfactory rating with results higher than 3. The two worst positions were the usefulness ($3.5 \pm 1.22, n = 14$) and the details ($3.46 \pm 1.05, n = 13$) of the slides. This indicated that the quality of the slides which was intended to be used as a script for the lectures were leading to a lot of other problems. The poor learning success ($3.14 \pm 1.17, n = 14$) and the overall impression ($2.86 \pm 1.23, n = 14$) of course were few indicators for this inference. The bad results (>3.2) in the quality of board writing were surprising since the board was usually not used. This is also reflected in the lower amount of votes for this indicator, which was just 5 when compared to the 14 votes for other indicators.

The work load was rated at 2.86 ± 0.86 ($n = 14$). Besides the above mentioned problems, the course was rated well or acceptable in the interconnection between theory and practice ($1.64 \pm 0.74, n = 14$), in the lecturer's preparation ($1.65 \pm 0.75, n = 31$), responsiveness ($1.79 \pm 0.89, n = 14$) and his (perceived) dedication ($2.43 \pm 1.22, n = 14$). The students stated that the basic essentials have been worked out well ($2.43 \pm 1.16, n = 14$) and that they understood the importance of the course for their further study ($2.0 \pm 1.0, n = 7$).

The last two indicators – basic essentials and importance of the course are in contrast with the learning success indicator. If a student understands that a course is important, he/she surely will be happy to learn for his/her own benefit. Nevertheless it seems that though the basic principles have been worked out and the student appreciates the importance of the course; there seems to be an obstacle hindering the student to get an overall appreciation of the topics which will give him/her a feeling of understanding them. Therefore with this analysis, one can arrive at the impression that the problem is more related to the structure and presentation of the content rather than a motivational problem from either the students' or from the lecturer's perspective. This is emphasized by some of the hand-written anonymous comments as well: "The slides don't have any explanations", "Learn effect is very low", "There is no clear structure of topics".

C. Goals and Curricular Requirements

Our main objective was to see a marked improvement in the lecture's LQI. As argued before, the general impression of the lecture, work load and course structure had to be improved to a value, smaller than 2.5, since these are the values affecting our LQI. The two other values of lecturer's motivation and his responsiveness were rated well as mentioned before.

As a general idea for the chosen topics, methods and technologies were brought in that were used in research in our own group. This should on the one hand modernize the curriculum; on the other hand give a better outlook and impression of possible research topics for the students. Also this gave the lecture the possibility to become unique in a way, since every research group may have different scopes.

A curricular requirement was to shift the basics of microscopes, telescopes and aberrations and their concepts to early lectures since this helped those students who were attending the optical design lab in parallel. Usually the students struggled with the understanding of the simulation tasks when they were missing these basic concepts, which led to a higher work load in the lab. Thus facilitating knowledge translation from theory to lab formed one of the boundaries in our restructuring exercise.

V. Revision and Its Measures

This chapter points out what measures were taken to improve the former mentioned indicators.

Structure, usefulness and details of slides and scripts were linked in the here taken approach because the slides are intended as a script. A graphical overview of the link between indicators and measures is given in Fig. 3.

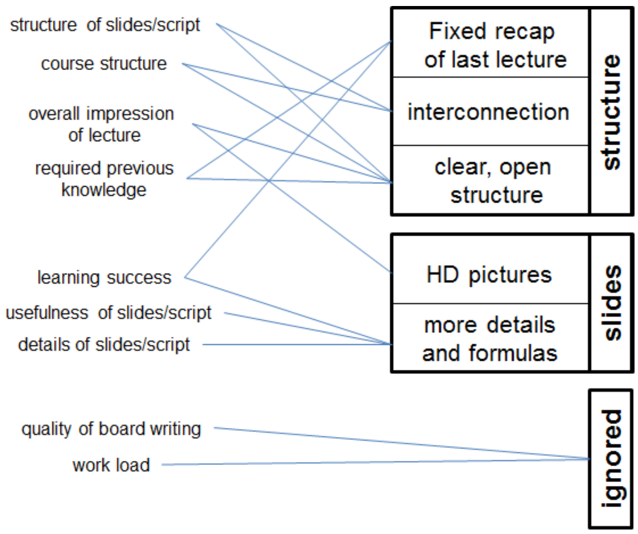

Fig. 3. Indicators linked to the improving measures.

We expected the course structure and the structure of the slides and the script as being improved by a clear, open structure and an interconnection ("red thread") between the lectures. The required previous knowledge should be positively influenced by these measures and a fixed recap of the last lecture as well. After the revision the addition of more advanced material made the lecture in fact a bit more difficult but it was believed that good interconnections and recaps might help the students to order it on simpler already learned concepts. The overall impression was intended to be influenced by the new structure and higher quality pictures. Pixelated images were deleted or replaced.

The learning success was a tricky position. Learning success is proposed as a subjective feeling. We added the fixed recaps at the start of each lecture to trigger this feeling and added more details and formulas to the slides. The latter measure should benefit the usefulness and the details of the slides and script as well. Due to former mentioned reasons we ignored the work load and the quality of the board writing indicators affecting the lecture. The only change was altering the tasks in the tutorials from a mandatory base to an optional one since student had shown no passion in solving the tutorial's problems.

The other effects of restructuring OE on tutorials were minimal. The tutorials contained problems based on different topics of lecture, and care had to be taken such that students were exposed to a particular lecture before problems on the same topic.

A. The Revised Structure

First a new structure for the course was considered. Upcoming technologies were emphasized and our own research was included wherever possible. The first four lectures were fitted to teach the basics to succeed in the Optical Design Lab as mentioned before.

It was considered to give first mathematical or physical background information and then applications. Examples are the combinations of "Ray optics" and "Popular applications" (e.g. ray optics to describe telescopes) or "Interference" and "Filters and mirrors" (Interference filters). This helped to get an interconnection between several lectures. The fixed recap at the beginning of each lecture showed the students that lectures were built on each other, so they could associate the new material with the former learned. In principle just few advanced or renewed materials had been added but the order of the taught material was changed to fit in a story line.

An overview of the new structure is given in Fig. 4.

1. Introduction and basics	8. Fourier optics II
2. Ray optics	9. Diffractive optics
3. Popular applications	10. Interference
4. Aberrations I	11. Filters and mirrors
5. Wave optics	12. Lasers and laser safety
6. Fourier optics I	13. Displays and projectors
7. Aberrations II	14. Open question and buffer slot

Fig. 4. Overview of order and content of the revised lecture structure.

A more detailed overview is given in the appendix, especially interesting for teachers of optical engineering courses.

B. Evaluation after the Revision

The lecture has been evaluated with its new structure and slides after our improvements in the next year (winter term 2012/2013), compare Fig. 5. The LQI has risen from 69.7 to 98.7. Apart from the importance of the lecture indicator (declined by 0.12), all other indicators showed improvement. Of the five key indicators mentioned, nearly all indicators meet our desired improvements as outlined in our scope. The overall impression of the course improved by 0.79 to a value of 2.07 ± 1.01 $(n = 30)$. The course structure was improved by 0.71 to a value of 2.43 ± 0.92 $(n = 28)$. Even the indicators related to the lecturer's responsiveness $(1.46 \pm 0.69, n = 28)$ and (perceived) dedication $(2.07 \pm 1.01, n = 30)$ slightly improved. Nevertheless the work load indicator could not be altered which was rated at 2.61 ± 0.99 $(n = 28.$

Year	2011/12	2012/13	Improvement
Previous knowledge	2.86	2.09	0.77
Details script	3.22	2.43	0.79
Structure script	3.33	2.64	0.69
Details slides	3.46	2.35	1.11
Structure slides	3.29	2.31	0.98
Helpfulness slides	3.5	2.84	0.66
Learning success	3.14	2.42	0.72
Acoustics	2.54	1.76	0.78
Overall impressions	2.86	2.07	0.79
Course structure	3.14	2.43	0.71

Fig. 5. Comparison of the SET results before and after the revision.

Other improvements are highlighted as well in addition to the five key indicators (compare Fig. 3). It should however be mentioned that some of the standard deviations are quite high (> 1). As a result improvement values which are higher than 0.6 are considered and other improvements are regarded as not so important or negligible. The strongest improvements were within the scope of slides: Their details indicator has increased by 1.11 to a value of 2.35 ± 0.98 $(n = 31)$, their structure has improved by 0.98 to a value of 2.31 ± 1.09 $(n = 32)$ and the usefulness advanced by 0.66 to a value of $2.84 \pm 1{,}11$ $(n = 32)$. The required previous knowledge improved by 0.77 to a value of 2.09 ± 1.04 $(n = 33)$. The acoustics in the room advanced by 0.71 to a value of 1.76 ± 0.96 $(n = 34)$.

C. Discussion of the Result

All in all our improvements are satisfactory. The majority of key indicators of the SET have shown improvement with values better than 2.5 except the working load. The fields for open comments in evaluation forms have mentioned that there is scope for more detailed slide sets.

The only indicator which was not influenced is the workload which has to be discussed first. It seems that the students include exercises from tutorial implicitly when they evaluate the work load of the course. In principle there is no need for students to complete the tutorial exercises and questions regarding the corresponding effort should not even be a part of this questionnaire because the exercises are evaluated separately. Luckily there are four other indicators which can help us to judge the workload issue. The students have to rate the course in consideration and comparison from other courses with relative indicators like difficulty level (1 – too low, 5 – too high), breadth (1 – too small, 5 – too much), tempo (1 – too slow, 5 – too fast) and the relative amount of work (1 – very small, 5 – very large) in comparison to other courses. The achievements were 3.03 ± 0.72 $(n = 34)$ for difficulty level indicator, 3.12 ± 0.48 $(n = 33)$ in breadth indicator, 3.21 ± 0.74 $(n = 33)$ for tempo and 3.21 ± 0.83 $(n = 28)$ for the relative amount of work. These values are nearly perfect which might reveal that students tend to perceive workload as always heavier than it is in principle which can be related to so called "The Paradox of Rigor" [5].

Another interesting aspect is the interdependence of the ratings. The structure and appearance of the slides were improved which resulted in enhancing the corresponding ratings significantly as intended (and as mentioned in the previous section). Nevertheless some improvements should be pointed out: The indicator for the need for prior knowledge in the subject significantly dropped. It seems that a clearer structure and more details on the slides lowered the barrier of prerequisite knowledge. Ample introductory material combined with clear interconnection between the topics in lectures helped as well.

As a non-intended effect, the acoustics in the room improved due to the fact that a headset microphone has been used this term.

The grades of students in the exams were not influenced in a dramatic way. Interestingly the average grade of the post review intake was a bit worse and the variance increased too. Oral exams in 2012 resulted in an average of 1.80 ± 0.44 ($n = 49$). Until the end of June of 2013 the revised lecture's students scored 1.91 ± 0.85 ($n = 47$)(A grade of 1.0 is very good and 4.0 is the last passing grade while 5.0 means failed.).

D. Discussion of the Evaluation Method

The LQI value can range from worst case (0) to best case (100). A global rating like the LQI is mainly a minimized tool for departmental revision purpose [9]. In this way it is quite legitimate but struggles due to the multi-dimensionality of teaching. Reaching a LQI value of 100 is not necessary for the revision board's satisfaction but it experiences have shown that it should be at least over 90 to avoid interrogations. The LQI tries to weight in five key indicators to get a fair impression of a course's rating but this can lead to some problems since there are over 40 indicators.

As mentioned before, the goal of the improvement was to enhance the LQI and thereby achieving an indication of improvement in teaching. From the SOTL perspective, a global rating is too simplified to rate the teaching and learning experience, nevertheless it is a good starting point. SOTL focuses on the free will of the teacher's self-examination for achieving a better transmission and transformation of knowledge as direct contributing factor in the student's learning experience [10]. Induced ad-hoc improvements achieved by isolated ratings will always have the bitter taste of sticking to numbers rather than to the overall quality advancements. This aspect can be seen with strong emphasis when considering that a global rating is always an average of different items. Therefore, the lecturer will always consider only the improvement of relevant key indicators which are accounted for in the global average. In our case these were just five out of over 40 items. Nevertheless, a detailed consideration of all the indicators is important. EFA suggests that an unsatisfactory rating in one item might just be the result of other items as it has been shown in the previous sections. Some of the items might also not be accounted in the teaching scheme of a course like the blackboard ratings in this lecture. Such results should be ignored along with those indicators whose votes are smaller than the half of the amount of the total voters.

As shown in the previous sections, while considering the work load indicator, it might be useful to change the weighting of the LQI's indicators by a function which is dependent on the difference of the optimum value of 3 in level, breadth and tempo of the course. This is typical for some other examination methods which are based on integrated Confirmatory Factor Analysis (CFA) [8], [14], [15], Hierarchical Confirmatory Factor Analysis (HCFA) [16] and Structural Equation Models (SEM) [17] applied specifically for SET analysis. In general the correlation between theory and practical experience would be a better indicator for an engineering lecture in our opinion. Especially because lectures are usually separated from exercises which are held as another course and have their own evaluation forms. These tutorials are usually intensive workload wise. This would prevent a mix-up of the students' opinions and evaluations between lectures and exercises. An important source or indicator for teaching improvement is the free text field. This can give a good overview of the most crucial issues, where students are able to jot down thoughts without being restricted by the scope of the questions. In the case of free text boxes, students should be given the opportunity to write their opinion anonymously in every rating. This does not mean that evaluations questions can be done away with entirely and only free text boxes. In addition, free text boxes help in supplementing the information gained from evaluation exercise. Otherwise, the ratings are just numbers without any solid content and lecturers have to take more effort to think about revision potentials.

The indicator for learning success is hard to objectively analyze. Students might think they understand more but this is a subjective point of view. In the end the learning effect determined by SET is just a measure of perceived satisfaction on the part of students [18].

VI. Conclusion

In this article the revision process for an engineering course (OE) based on the students' evaluations is documented. The impact of the revision in the subsequent evaluations is analyzed and comparisons are made. The ratings are improved by taking into account parameters or feedback from the students' evaluation. The principles of the explorative factor analysis (EFA) were used to enhance in several topics by targeting a few critical indicators. Interdependencies are shown that influence the learning success and prerequisite knowledge requirements with the structure of the course and amount of details in the slides.

The benefits and issues of a rating system and a global rating are discussed which can help to maintain a minimum of teaching quality but it is advisable that any revision of the course has to be based on an in-depth analysis.

For the winter term 2013/14 all related lectures and exercises have been rated with a LQI of 100.

Appendix

A. The Detailed Revised Structure

As a starting point the very basics of optical physics and a short review of its topics are taken in the first lecture. The second lecture is to be an introduction to ray optics. Ray optics gives the tools to handle popular applications that will be covered in the third lecture (magnifying glass, microscope, telescope, human eye). The fourth lecture explains the aberrations in general while focusing on both chromatic as well as monochromatic aberrations. At this point enough theory is explained to facilitate smooth progress of the optical design lab in Zemax. The ODL consists of nine sessions as opposed to thirteen or more for OE, thus the ODL has a deferred start to facilitate effective knowledge transfer between theory and practice (which is reflected in one of the indicators).

Lecture 5 is about the general wave like behavior of light. It provides a brief look at phenomena (diffraction, interference) which can be explained using the wave nature of light. To gain further knowledge of analytical tools involved in design and evaluation of optical systems one needs to have a background in Fourier optics. This topic was split into two lectures. In Fourier optics I (lecture 6), the interdependence of the frequency with space and with time is covered. The Airy disc is introduced here which is a starting point for the more mathematical approach covered in advanced optical aberrations in Lecture 7 using point spread functions, modular transfer functions and Zernike coefficients. Lecture 8, called Fourier optics II, also happens to be most mathematical in nature of the whole course. It investigates the imaging under coherent and incoherent illumination using Fourier analysis.

The topic of diffractive optics in lecture 9 deals with diffractive elements and their use like the setup of spectrometers, holography and bifocal intraocular lenses. Lecture 10 focusses on the topic of interference. Here it is shown how interference can be used as a measuring tool - CD/DVD/Blu-Ray technology for saving information and laser Doppler interferometry for measuring speed of manufacturing machines or wind speed. Lecture 11 deals with filters and mirrors. For the sake of repetition filters based on interference like antireflection filters are dealt first. Later on, advanced filters such as omnidirectional filters like the Christiansen filter, absorption and polarization filters are covered. In the mirrors section the mirroring principle and the new technology domain of micro mirrors are focused.

Lecture 12 is about lasers and laser safety. Since this is an Engineering based course, the theory behind lasers is skimmed over. Most common setups of lasers and some advanced principles of nonlinear modulation are explained. Half of this lecture focuses on the principles of lasers while the other half is concerned with laser safety issues and the understanding of the laser standard [19]. From an engineering point of view, it is not only important to understand the functionality of these sources but also to know about the safety measures which have to be taken if one wants to build and use these devices. E.g. the choice of correct laser safety goggles is covered in this lecture. An early introduction of laser theory is not necessary sinceKSOP students attend a parallel lecture just focusing on lasers and undergraduate students attended a mandatory lecture covering this topic before.

Lecture 13 is about displays and projectors. It deals with the topics of display properties like pixel size, resolution and aspect ratios on standard screens, data glasses and the upcoming laser projection technologies.

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Thorsten Beuth received a MPhys. (Hons) degree in optoelectronics and lasers by the Heriot-Watt University, Edinburgh, United Kingdom, in 2009 and a Dipl.-Phys. degree in general physics by the Karlsruhe Institute of Technology, Karlsruhe, Germany, in 2011. He currently works as a member of the Scientific Staff at the Institute for Information Processing Technologies at the Karlsruhe Institute of Technology, Karlsruhe. His research interest focuses on laser remote sensing technologies.

Mr. Beuth was awarded scholarships by DAAD, SAAS and KSOP and the certificate for higher education teaching of all universities within the state of Baden-Württemberg, Germany.

Svetlana Danilova received her B.Sc. and M.Sc. degrees from the Department of Photonics and Microwave Physics and graduated from the Faculty of Educational Studies with teacher qualification certificate at the Lomonosov Moscow State University, Moscow, Russia, in 2012.

She currently works as a member of the Scientific Staff at the Institute for Information Processing Technologies at the Karlsruhe Institute of Technology, Karlsruhe. Her research interests include biometric technologies and biomedical imaging.

Harsha Umesh Babu was born in Banglore, India, in 1982. He received the B.Eng. degree in electronics and communications from Visvesvaraiah Technical University, Belgaum, in 2003 and M.Sc. degree in electrical engineering and information technology from Universität Karlsruhe (TH), Karlsruhe, Germany, in 2008. In 2013 he received his PhD in electrical engineering and information technology at the Karlsruhe Institute of Technology, Karlsruhe, Germany.

He worked as a software engineer in India for various companies from 2003 to 2006. In 2009, he joined Institute for Information Processing Technologies as a member of Scientific Staff. He currently works as an engineer at Continental AG, Lindau, Germany. His research interests are optical system design, product security and image processing.

Siegwart Bogatscher received a Dipl.-Ing. in electrical engineering and information technology by the University Karlsruhe, Karlsruhe, Germany, in 2009.

He currently works as a member of the Scientific Staff at the Institute for Information Processing Technologies at the Karlsruhe Institute of Technology, Karlsruhe. His current research focus is 3D imaging using MEMS-based Time-of-Flight laser scanners and their applications.

Leilei Shinohara received his B.Eng. degree in system and control engineering in 2006, the M.Eng. degree in mechanical and control engineering in 2008 from Tokyo Institute of Technology, Tokyo, Japan.

He currently works as a member of the Scientific Staff at the Institute for Information Processing Technologies at the Karlsruhe Institute of Technology, Karlsruhe. His research interests are optical remote sensing technologies and optical system design.

Nico Heussner received a Dipl.-Ing. in electrical engineering and information technology by the University Karlsruhe, Karlsruhe, Germany, in 2009.

He currently works as a member of the Scientific Staff at the ForschungszentrumInformatik, Karlsruhe. He once worked as a member of the Scientific Staff at the Institute for Information Processing Technologies at the Karlsruhe Institute of Technology, Karlsruhe. His research interests are within the field of optical measurement techniques and laser-tissue-interaction.