# An introductory course on automotive lighting

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## ABSTRACT

A course has been developed for students interested to learn practical design procedures for automotive lighting applications. The course covers topics such as imaging and non-imaging optics, LED lighting, plastic optics, plastic part design, optical manufacturing, injection molding, optical tolerancing, computer aided lighting and computer aided design, and economical aspects of product development. The students work through several projects on rear lighting and forward lighting. The present paper summarizes the pedagogy in optics education in the second offering of the course, inspired by the experiences from the first offering, the feedback from students, and the feedback from industry. Challenges faced during teaching the course, both technical and pedagogical, are discussed.

**Keywords:** Automotive, lighting, illumination, education

## 1. INTRODUCTION

Optical Engineering (OE) program at Rose-Hulman Institute of Technology started to grow within Bachelor of Science degree in Physics which has been established since 1958. The department started offering an area minor program in Applied Optics in 1983. In 1985 a Master of Science degree in Applied Optics was offered and the Center for Applied Optics Studies (CAOS) was established. In 1988, an industry-oriented undergraduate program in Applied Optics was offered, which was renamed in 2002 to Optical Engineering. Training top-skilled engineers for the industry and higher education through rigorous courses and laboratories with ample exposure to hands-on experiments and engineering tools is a cornerstone of the OE program at Rose-Hulman Institute of Technology. Interestingly, Rose-Hulman Institute of Technology is uniquely situated in the Midwest region, in close proximity to major manufacturers in automotive lighting industry such as North American Lighting (NAL), VALEO, Flex-n-gate, and several other lighting and illumination companies. It is indeed beneficial for OE students who wish to remain local to the area or who find an interest in illumination optics to join such companies. Additionally, learning legal illumination practices enables the students to join other big industries such as general illumination or non-imaging optics as lighting engineer, illumination engineer, display engineer, or in similar job functions. However, entry level engineers may require months of training to become productive in this particular industry because no course exist at any school to prepare engineers to fill in the role of automotive lighting engineer right away.

The global automotive lighting market is estimated to be USD 34.9 billion in 2025 [1]. The demand for automotive lighting and illumination engineers is at all time high since the technology is evolving very fast in solid-state lighting with new and better light-emitting-diodes (LED), µLEDs, and flip chips coming out rapidly to the market. Gladly, the up-to-date engineering tools make it very feasible to have access a large portion of design space in the field. This opportunity was identified by the author and hence an effort was put together for developing a course in order to address the demands of industry for engineers adept at lighting and illumination, especially for automotive industry. The following section describes the details of the developed course. The course was made open to engineering majors in optical engineering, mechanical engineering, and electrical engineering. The level of students was not limited, so any student from freshman up to master's students could participate (and did), making it a versatile course throughout the institute.

## 2. COURSE DETAILS

In the big picture, the goal of the course for the students has been to provide them with hands-on engineering tool, experiencing practical applications, and realistic constraints. On the practical applications, in the automotive industry, there are different types of lamps, each with their own legal requirements. Most important lamps are either used for forward lighting or rear lighting. Forward lighting includes the low/passing beam (LB) and high/driving beam (HB), and

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rear lighting includes stop, tail, turn (STT) lamp and center-high-mounted-stop-lamp (CHMSL). Other than these four major lamps, fog lamp, marker lamp, daytime running lamp, backup lamp, cargo lamp, and a few others exist. There is indeed not enough time to go over all of them. In order to select the lamps to be practiced during the course, it has been noted that there is only ten weeks available to the students since Rose-Hulman Institute of Technology is on a quarter-based system rather than semester-based. This restriction puts a limit on the number of practical lamps to be exercised, and hence challenges the pedagogy employed. On the other hand, the design of a lamp, even a simple lamp, may take weeks in industry, in order to analyze all the aspects before the launch of the product. That is another factor to consider for designing the course on automotive lighting. Adding the time needed to teach the prior knowledge necessary for the design purposes further restricts the time available for project work. In summary, the three time constraints listed above limit the amount of expertise gained by the students, therefore an efficient pedagogy is to be employed.

For such a comprehensive course on automotive lighting, a variety of prior knowledge is to be taught in order to enable students to truly design functional, acceptable products. Therefore, course objectives were established firsthand. The course objectives listed below indicate the skills obtained by the students after successful completion of the course:

1. Understand the different types of light sources such as incandescent, fluorescent, and solid-state
2. Understand photometric units such as lumen, lux, candela, and photometric measurement procedures using goniometers and integrating spheres
3. Understand color measurement, CIE Color system, Color perception and vision
4. Read and employ datasheets of LED light sources
5. Understand the economics of high-volume production
6. Understand design for manufacturing
7. Understand robust design
8. Understand how to read and comply to standard documents such as federal and international rules and regulations
9. Understand environmental effects of product design
10. Understand the marketing of the product and consumer preference by investigating the road patterns of different lamps
11. Design robust, manufacturable, legal products for forward lighting and rear lighting
12. Use computer-aided-design and computer-aided-lighting tools for product design

Based on the course objectives, a number of topics were selected for the course. The course topics are listed below:

1. Light and Lighting Review: Properties of light, rays, waves, photons; electromagnetic radiation, spectra. Optical properties of materials.
2. Photometry Concepts for Lighting Systems; lighting measurement units;
3. Color, Perception and Vision: Color concepts, Munsell and CIE Color System; chromaticity coordinates; correlated color temperature, color rendering index; color mixing; specifications and measurements.
4. Sources Types: incandescent, fluorescent, high-intensity discharge, LEDs.
5. Computer aided lighting: Monte-Carlo ray tracing, Simplified source modes, Ray files, backward ray tracing.
6. Legal requirements: lamp sizes, lamp colors, test points.
7. Design for manufacturing: injection molding, plastic part design, draft angles, undercuts, poka-yoke, versatile design with symmetry, robust design and tolerancing.
8. Hands-on project work. Delivery of results and presentation of results.

Based on the course topics and course objectives, a number of reference texts were selected to teach the materials from and to be used by students. Three resources were used as the textbooks, based on the access level of the students to SPIE Digital Library [2]:

- SPIE Field Guide to Illumination [3]
- SPIE Field Guide to Molded optics [4]
- SPIE Field Guide to Geometrical optics [5]

It was also revealed that the automotive lighting course may have a good overlap or complementary to a less application-specific course coded "OE 434", entitled Non-Imaging Optics on the department catalog. However, the huge emphasize of the currently offered course on training students for product design, and the depths of skills gained by the students distinguishes the Automotive Lighting course from any other courses offered in the department.

The course on automotive lighting has been planned to be a project-based course in which the students learn the materials and the desired skills by working on several design projects. Four projects were eventually selected, each on designing a particular vehicular lamp, considering their educational values, skills gained, and time restrictions. Two projects on rear lighting to work on CHMSL and STT, and two projects on forward lighting to deal with HB and LB. The order of introducing the projects in the second offering of the course was decided to be CHMSL, STT, HB, LB keeping in mind the difficulty level in design of each lamp. The rationale behind this is that the rear lighting incorporates simpler optics, and simpler legal requirements. Also, the sources for rear lighting would only be red colored LEDs, therefore material contribution is minimized, making the design considerations simpler than forward lighting.

The types of optical components practiced in the course was limited only to 1) reflector optics such as reflector cups, 2) refractor optics such as Fresnel lens, 3) total internal reflection (TIR) optics, also known as collimator optics, 4) and MacroFocal reflector optics which is the basis for segmented and multifaceted reflector. This conclusion was made after the first offering of the course in which more sophisticated optics were introduced to the students, such as light pipes and genetic algorithm optimizer, but they may have overwhelmed the students. Therefore, in the second offering it was arranged to cover less but teach more. In addition, as opposed to the first offering of the course, the practice of the aforementioned optical components were divided among the four projects, rather than teaching them all at once. This approach in teaching the skills turned out to be very convenient and more receptive for the students, since their designed products were much better than those of the first offering of the course.

### 2.1 Engineering tools

**Computer aided lighting (CAL)**

The engineering software used for practicing the topics pertinent to optics of the course was Synopsys Lucidshape [6]. According to the software "LucidShape is the most powerful and advanced computer aided lighting design software for automotive lighting design tasks. With dedicated algorithms optimized for automotive applications, LucidShape facilitates the design of automotive forward, rear and signal lighting, and reflectors". Indeed, Lucidshape is an effective teaching tool too since the organization of the functions and components was easy to understand by students, the ray tracing engine was very fast, the integrated CAD geometry was easy to use, and there were graphs and tables dedicated to the automotive industry applications. The software also notes that "LucidShape's MacroFocal feature for the design of multifaceted reflectors has been augmented with state-of-the-art freeform design capabilities to provide more granular control over light spread, enabling the specification of two-dimensional light target distributions. The new freeform surface capabilities allow designers to minimize or eliminate the need for multiple rows of facets. As a result, stray light caused by gaps between facets can be minimized, flux collection is maximized, and designers can have more freedom to focus on styling and appearance. In addition, the new capabilities can simplify manufacturing-related processes such as reflector metallization and tooling."

**Computer aided design (CAD)**

Along with Lucidshape as the primary CAL tool for designing the optics, a CAD tool was needed in order to practice the aspects of product development and teach plastic part design. Two options were provided to the students: Solidworks [7] and Rhino [8]. Most of the students have taken a course in their first academic year to exercise modeling in Solidworks. However, the author's experience in Rhino and the incredible ease of handling geometrical objects by Rhino led to introduction of Rhino as the alternative CAD tool preferred by the course instructor. It was observed early in the course that most of the students ended up switching to Rhino after witnessing and watching the CAD work demonstrations in the classroom by the instructor (who is the author of the present document). Also, it was experienced by the students that the integration of Rhino and Lucidshape is seamless such that geometries can be transferred back and forth without any loss of information.

Table 1. Gantt Chart of the course on Automotive Lighting

| Projects | Topics Practiced | Weeks 1-10 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Intro | Review of Optics, Intro to CAL, Synopsys Lucidshape | o | o | | | | | | | | |
| Project #1<br>CHMSL | Reflector optics, LED Datasheet: (Binning, I-V curve, emission pattern), Legal Test points, Federal Rules and Standards, CAL, Monte Carlo ray tracing, Plastic part design, CAD a full lamp assembly, Robust design, Tolerancing, Design for manufacturing, economic analysis and cost estimate | | | o | o | | | | | | |
| Project #2<br>STT | TIR optics, Refractor optics, LED Datasheet: (Binning, I-V curve, emission pattern), Legal Test points, Federal Rules and Standards, CAL, Monte Carlo ray tracing, Plastic part design, CAD a full lamp assembly, Robust design, Tolerancing, Design for manufacturing, Lit appearance, Economic analysis and cost estimate | | | | | o | o | | | | |
| Project #3<br>HB | Basic Macrofocal reflector optics, High Power LED Datasheet: (Color Temperature, Color rendering index, Light safety, Binning, I-V curve, emission pattern), Legal Test points, Federal Rules and Standards, CAL, Monte Carlo ray tracing, Robust design, Tolerancing, backward ray tracing, pattern diagnosis, Ray files, road illumination, Bird's eye view, driver's view | | | | | | | o | o | | |
| Project #4<br>LB | Advanced Macrofocal reflector optics, High Power LED Datasheet: (Color Temperature, Color rendering index, Light safety, Binning, I-V curve, emission pattern), Legal Test points, Federal Rules and Standards, CAL, Monte Carlo ray tracing, Robust design, backward ray tracing, pattern diagnosis, road illumination, Bird's eye view, driver's view | | | | | | | | | o | o |

## 2.2 The course approach

Table 1 shows the schedule of the course in a Gantt chart. So far, the course topics and objectives are decided on, the design projects are decided on, the optical components to be used for the design projects are decided on, the CAL and CAD tool were decided on, and the textbooks are also decided on. The order of introducing the projects in the second offering of the course was decided to be CHMSL, STT, HB, LB keeping in mind the difficulty level in design of each lamp. The approach to cover the materials is as follows. Reflector optics was practiced for CHMSL design and refactor optics was practiced for STT design. This approach was decided based on the feedback from students during the first offering of the course. During the first offering, both the refractor optics and reflectors optics were taught to the students and then they were asked to use them in the CHMSL and STT projects as they wished. The results were not ideal since students were confused how to select which optics to use for which project, and some tried both of the optics to see which one is better, therefore some portion of their project time was wasted, leading to requests for extension of deadlines in each project.

Considering the prior experience, in the second offering of the course, the decision was to limit the confusion and design freedom of the students by teaching one optics per project. That is, reflector optics was taught for CHMSL project and then students were asked to deliver their CHMSL designs according to a set of constraints. Next, the refractor optics was taught for STT and then students were asked to deliver their STT designs according to another set of constraints. This isolation of topics and projects proved an effective method of teaching and practicing the topics. As in a hidden curriculum, the students eventually realized that they could have used any of these optics for any of the projects, however the approach to introduce them into the projects helped significantly in their confidence and learning outcomes. This progressive approach also helped the students to manage time better.

Further, to teach design for manufacturing such as plastic part design and the rules for draft angles and undercuts, the students were asked to design the CHMSL and STT lamps in full assembly rather than just the optics of each lamp. The lamp assembly for CHMSL and STT project includes the optics, housing, LED board, and the methods of locating each component to a reference, poke-yoke, mounting, harness holes and etc. This additional task was to add more learning opportunities for engineering students in order to learn considerations for volume manufacturing, and also practice CAD work over the time of the first two projects. In addition, such practices are helpful since students can function better in future when they join cross-functional teams with mechanical engineers, electrical engineers, and manufacturing engineers present, and can understand their view of the project to communicate effectively.

In the following sections, the projects, their constraints, their scoring items, and some design examples submitted by the students in the second offering are presented.

### 2.3 Project #1 CHMSL

**CHMSL Constraints**:

- Pass US FMVSS 108 regulations.
- The CHMSL will be sent for volume production (1 million parts per year). Keep the costs minimal.
- Material options are PMMA or PC.
- For reflector optics, keep in mind that a second step (means cost!) is needed to create a reflective coating inside the reflectors (Vacuum aluminizing). Also keep in mind that the finishing process won't provide 100% reflectivity, but only 80%.
- You are free to choose any number of LEDs with a minimum of 1 LED (for obvious reasons).
- Your design must be manufacturable with injection molding process in mind (uniform wall thickness ~ 2mm and draft angles > 3 degrees).
- You are free to choose any final geometrical shape for your product design (bar, rect, round, oval, etc.).
- You need to provide the bill of material (BOM) with cost estimates (LEDs, Tooling, Material, Parts).

**CHMSL Scoring:**

- The project is reported on-time. All the deliverables provided as required, no errors.
- The project report follows the template. (1. Executive Summary, 2. Renders, 3. Drawings, 4. LED info, 5. BOM and Cost estimates, 6. Nominal design, 7. Tolerancing)
- The nominal design is robust, better than 150%.
- The design is robust and tolerant. (150% legal with at least a tolerance of ±0.2 in x&y)
- The design is manufacturable.
- Quality of CAD work for product design. (design of housing, design for assembly, locating the parts, poka-yoke, symmetry, smooth outer surface)
- Penalty: No Executive Summary. Penalty: Tolerancing not included, incomplete or incorrect. Penalty: Late submission.
- Bonus: The product is visually pleasing, creative and unique.

### 2.4 Project #2 STT

Design a 4" round STT lamp. Toward this project, two types of refractive optics were introduced to the class. One of them was the Fresnel lens optics and the second was TIR optics. Students had freedom to choose any of the options. Also, obtaining the lit appearance of a lamp was taught to students in order to prepare them communicate with a potential client or with a marketing department. It was asked that the students provide the lit appearance of tail and stop functions of their legal designs. Some selected submissions are shown in the design example section.

**STT Constraints:**

- Pass FMVSS 108. You need to pass the test points for BOTH the tail function as well as for stop function. You may choose to group LEDs to separate the functions or change the brightness of all the LEDs at the same time.
- Keep in mind to design for manufacturability, design for robustness, and design for selling a product!
- Material options are PMMA or PC. Only use lens optics.
- You are free to choose any number of LEDs with a minimum of 1 LED (for obvious reasons).
- Your design must be manufacturable with injection molding process in mind (draft angles > 3 degrees).
- The final geometrical shape for your product design MUST be round (circular).

**STT Scoring:**

Scoring the STT project was similar to CHMSL project.

### 2.5 Project #3 HB

The third project was arranged to transition from rear lighting to forward lighting. That means that students will need to use white LEDs rather than red colored LEDs. The HB is an easy lamp, therefore it provides opportunity to introduce more of the necessary skills for students. For example, the material dispersion was introduced in this section since the range of wavelengths was wide and over the full visible spectrum. The white LED light sources were introduced and the methods of making white LED were reviewed. Students were asked to investigate some of the manufacturers of automotive grade LEDs such as OSRAM, CREE, Nichia, LUMILEDs to familiarize themselves with the types and shapes of LEDs. Also, the high-power LEDs and their health risks were introduced. A sample high power LED with 1500 lumens was demonstrated in the classroom for students to get a sense of amount of light produced by such high-power LEDs.

Another concept that was introduced in this project was the ray files and how to incorporate them in the CAL in order to ensure realistic simulations. Ray files are the resources provided by the LED manufacturers as they spatially measure the real rays emitted by the LED. Therefore, instead of using an ideal rectangular or circular Lambertian emitting surface, the students learned to use the recommended, realistic rays for accurate simulations. The concepts of color temperature and color rendering index were also introduced in this project. Legal requirements of high beam were reviewed and different classes of lamps were studied. Students also were taught to obtain an estimate of the illuminated range of HB lamp on the road and they were required to report it for their own designs. The better range meant a better lamp. Chromatic ray tracing was also introduced in this part to accurately simulated emission spectrum of white LEDs.

The progressive introduction of materials in the second offering proved to be much more effective compared to the first offering. In the first offering, all the topics such as different types of optics, ray files, and other complex topics were taught first, and then students were asked to start on the projects. That approach caused confusion and also limited the time available for students to work on actual projects. In contrast, the progressive gradual introduction of more advanced skills helped students learn more efficiently and manage time better to deliver good designs in each project.

**HB Constraints:**

- High Beam to pass FMVSS 108
- Lamp must meet class UB1 requirements
- Light source must be LED
- There is no need for CAD work in this project

- Use reflector optics only. Set reflectivity to 80%.
- You may choose to use a single LED with the lumen range of 500-1500 lumens and CCT >5000K.
- The reflector size should be between 50mm to 200mm in diagonal.

**HB Scoring**

- The nominal design is legal and better than 150% min FMVSS 108.
- The design is reported with details as instructed.
- The design is robust and tolerant. (150% legal with at least a tolerance of +0.2 in x&y)
- Bonus: Design is compact (having a diagonal of less than 70mm)
- Penalty: No Executive Summary. Penalty: Tolerancing not included, incomplete or incorrect. Penalty: Late submission. Penalty: Range not reported.

### 2.6 Project #4 LB

The final project of the course was to design a low beam lamp. Only the reflector was needed to be designed where advanced features of MacroFocal optics in Lucidshape were taught. The LB legal requirements is very complex and hard to achieve, especially in the time duration of only two weeks. As an example, the test points of a LB class LB3V are shown in Figure 1 with 26 points, zones, and gradients in total. Some test points are tightly located which makes it really challenging, even for an experienced engineer. It should be noted that a well analyzed LB could take weeks to be completed due to the difficulty of legal test points and tolerancing sensitivity. Therefore, the project #4 was only to obtain a nominal design. CAD work, ray files, or tolerancing were not included to ensure that students can achieve the satisfactory results within the available time.

The only option provided in the fourth project was that this was also the final project or the final exam of the students. Therefore, considering the amount of new skills and insights students had learned along the way, it was permitted that students could submit a revised version of their previous lamps to fix the issues were noted to them in their individual design review.

**LB project constraints**

- Light source type: LED. Only a single LED with flux range of 500-1500 lumens.
- LED must have a CCT > 5000K.
- No ray files, only rectangular light source.
- Should have a reflector of diagonal size in the range 50mm to 200mm.
- May use a reflector shape of rectangular, round, or oval.
- For reflector optics, the reflectivity should be no more than 80%.
- Must be 120% legal.
- No tolerancing.

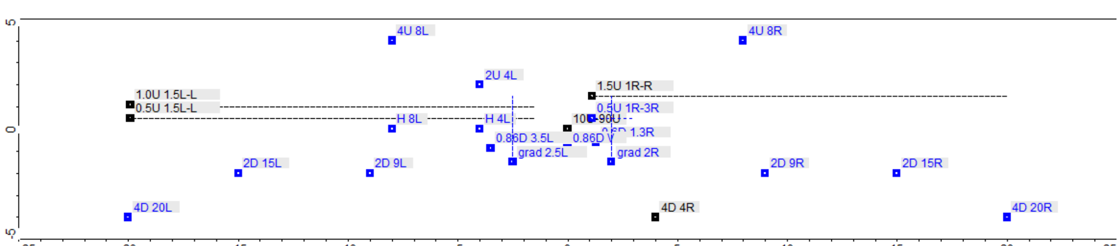
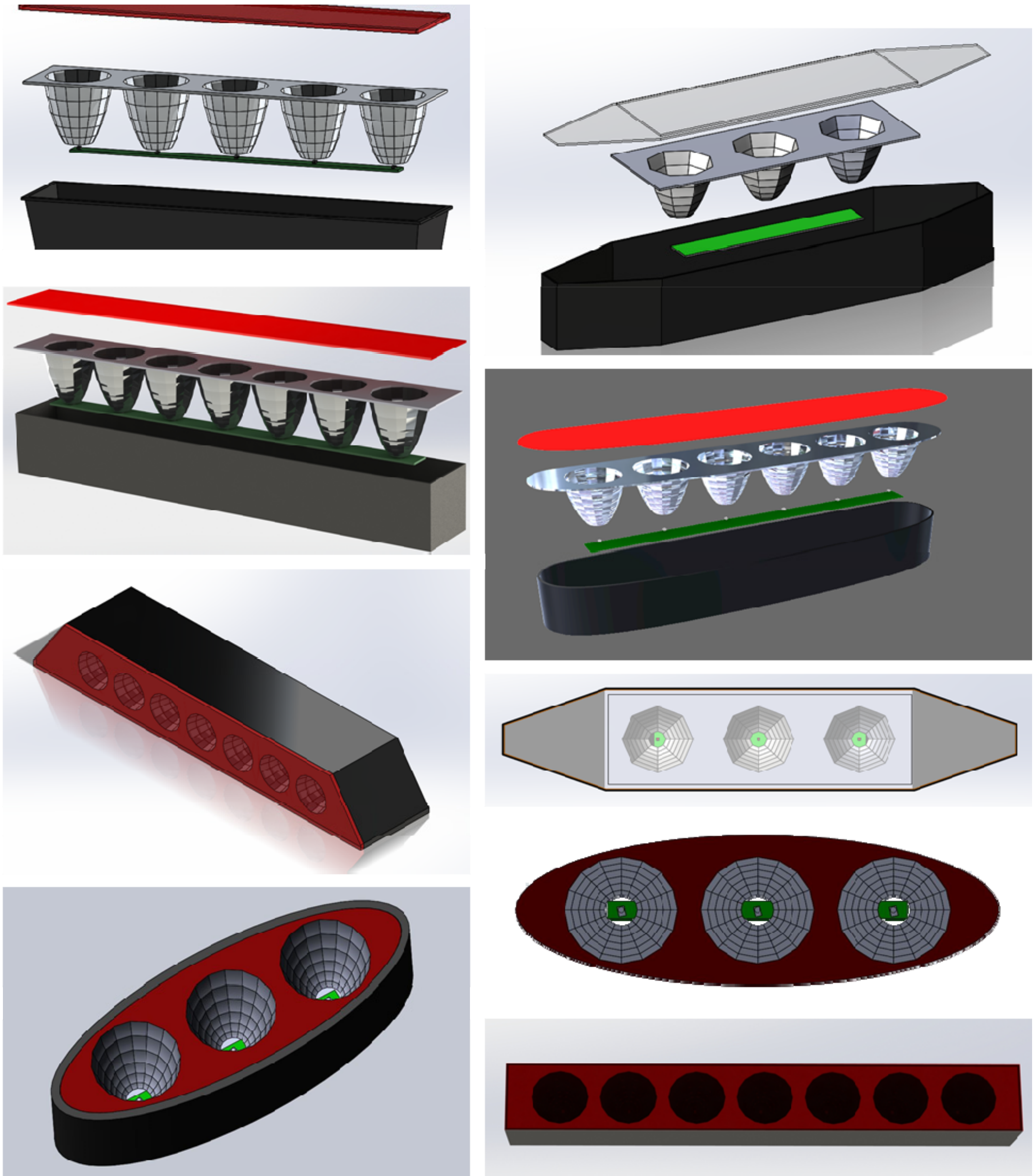



Figure 1 – Test points of LB3V according to FMVSS 108.

## 3. DESIGN EXAMPLES BY STUDENTS

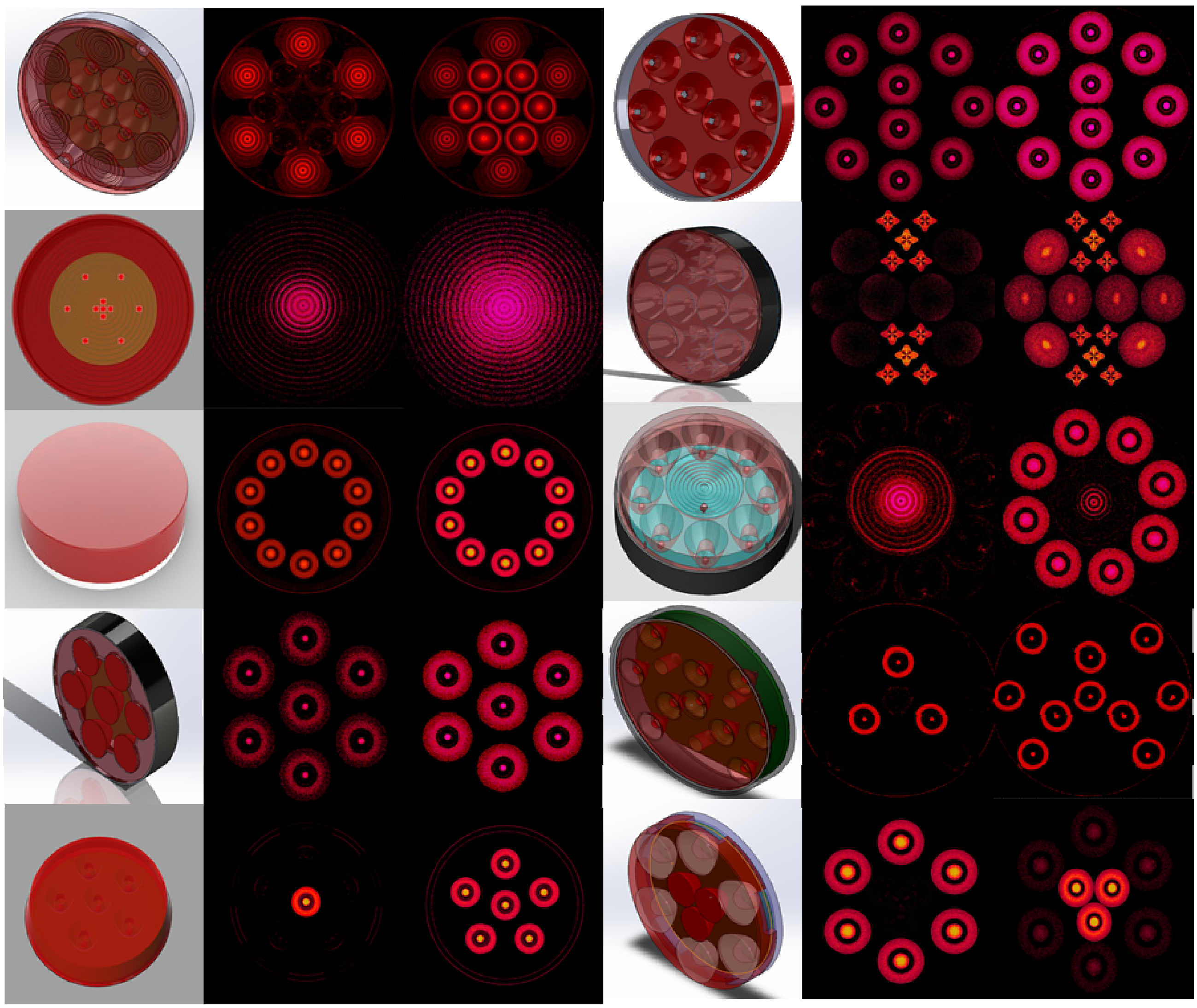
### 3.1 CHMSL Example Designs:

For this project, the students were required to ensure each part is solid, suitable for injection molding, with proper wall thickness and draft angles. The engineering drawings were also required. Note that these designs were completed in only two weeks, after only two weeks of training. This was the first time students design a complete product.



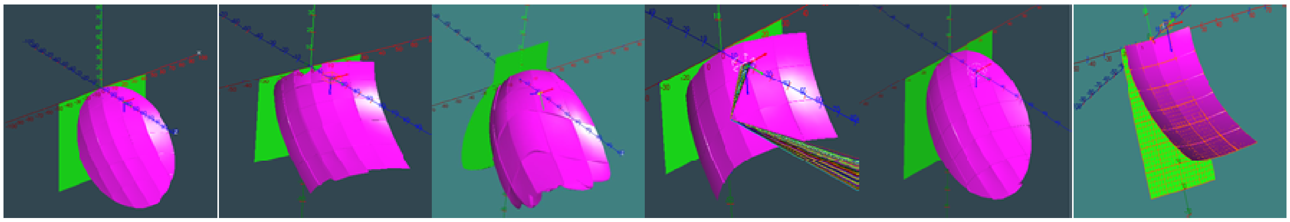
### 3.2 STT Design Examples

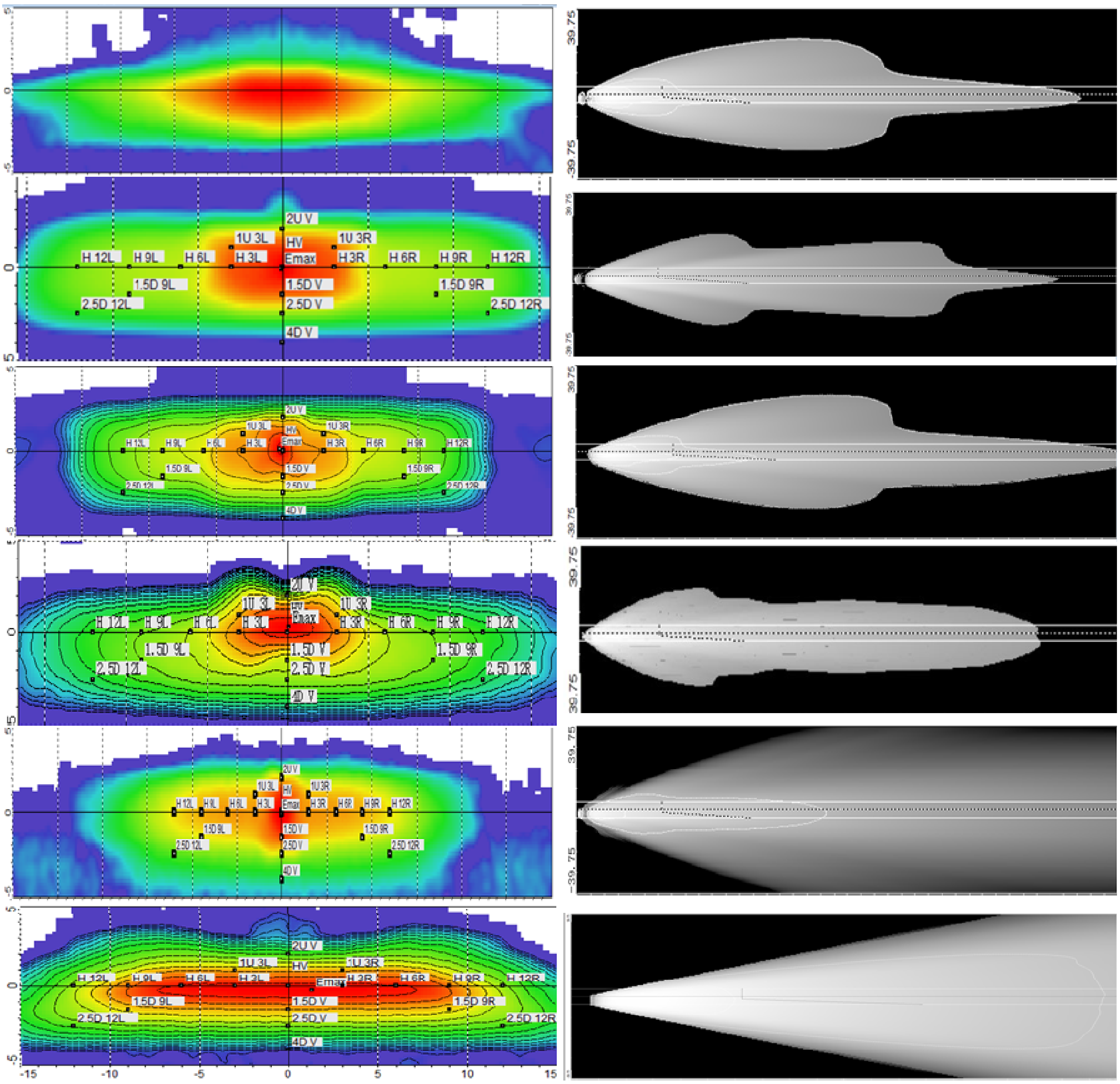
The STT project was a full lamp assembly just like CHMSL project. All the designs shown below are done by students in two weeks. All the designs meet the legal test points. Students were required to obtain lit appearance for tail and stop functions of their lamp. Different approaches are clear from the selected designs below. Some students used the Fresnel optics, some TIR optics and some combined the two.



## 3.3 HB Design Examples

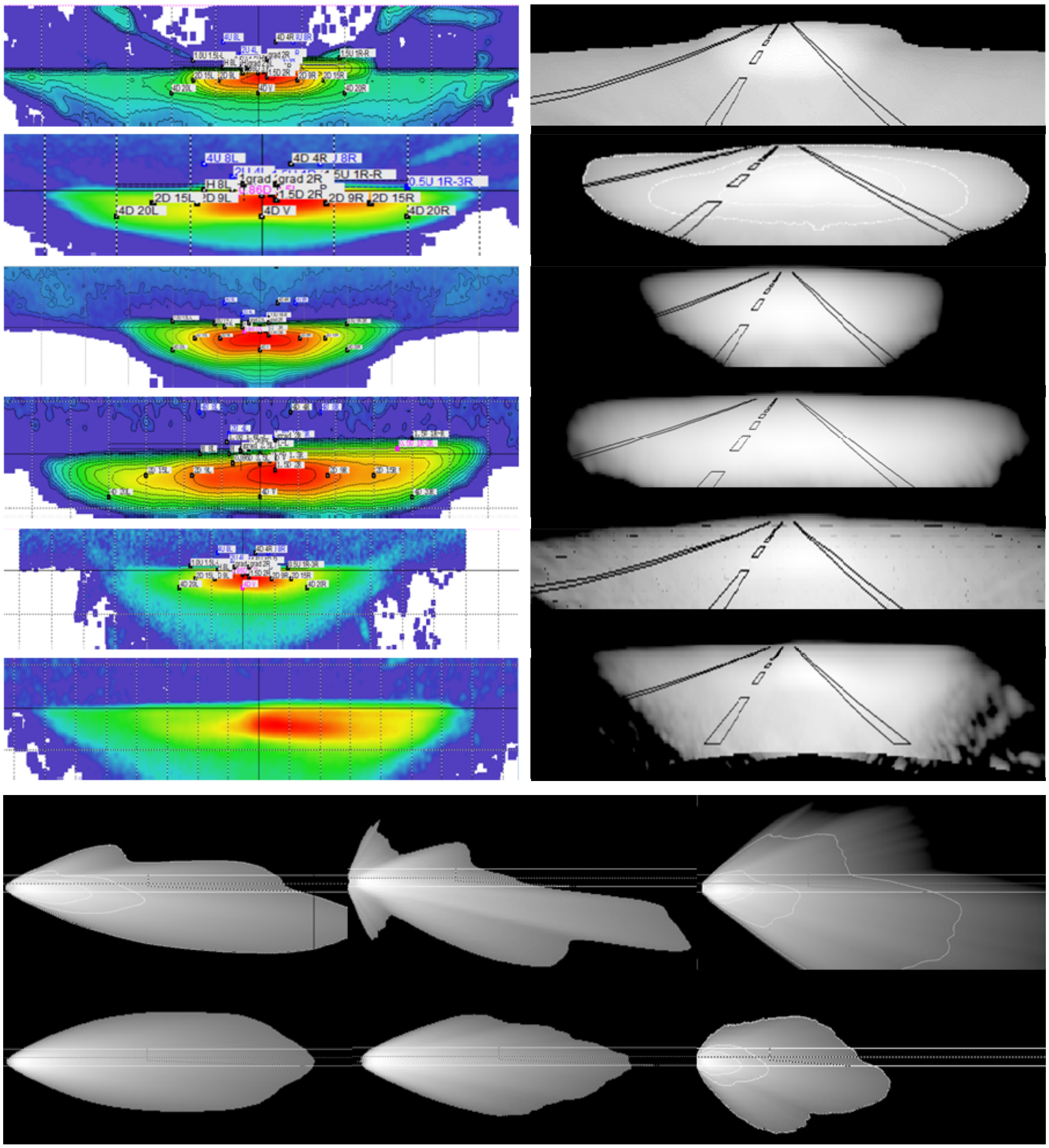
In the HB project, students were only using the basic features of MacroFocal in order to design segmented reflectors for meeting the legal requirements. The reflectors and light patterns are shown below. The students were also taught how to obtain the bird's eye view of the lamp when the HB is actually mounted on a vehicle and the road is illuminated by it. The greyscale bird's eye view for a couple of submissions are shown as well.





### 3.4 LB Design Examples

For the LB project, the students used advanced features of MacroFocal in Lucidshape in order to create legal cut-off required in the standard documents. It was discussed in the class that meeting legal test points is just the beginning of the design and they should think about consumer preference. Therefore, some students designed LB lamps with wider road illumination to be legal and to help the driver see better. The light pattern to meet the test points and the driver view simulated in Lucidshape are shown below. The bird's eye view of them are also shown.



### 3.5 Student Feedback

Students provide official feedback through anonymous evaluations at the end of each quarter. The evaluations are designed by office of assessment at Rose-Hulman Institute of Technology and are collected online in a learning management system. Some of the questions and feedback by students are provided below:

- Please rate the quality of your learning in this course: 33.33% rated Excellent and 66.67% rated Very Good. Reasons for such rating were:
    - "detailed videos for each project" was posted
    - "lessons were very easy to follow"
    - "very interesting and provided very valuable information for anyone looking to work in illumination engineering."
    - "directly related to industry."
    - "Working with actual legal standards and doing real projects for this course with many of the real manufacturing concerns has been extremely nice."
    - "I have really liked the projects"
    - "I was learning new software and I came out of the class feeling like I knew the software decently well."
    - "lectures were very detailed and straight to the point."
    - "I learned a lot about the inner optical design of automotive lighting in a way that's easy to connect back to prior work with optical systems."
    - "I also got to obtain some experience dealing with varying levels of standards and the difficulties that come with tailoring your design to them."
- Describe one or more strengths of this course.
    - "This class is very related to application of Lucid shape in real world, which could make me much more competitive in the job market."
    - "I thoroughly enjoyed this class, this is the first class where we applied what we learned in all of our optics class. It really puts into perspective what 'Optical Engineering' means. Wish there were more classes like this."
    - "We were given a lot of freedom in our projects so long as we were able to stay within the constraints. We also got to learn how to use an industry software for modeling and comparing to standards."
    - "I thought the biggest strength of this course was learning a software that is used in the industry. The video lectures were excellent because you could watch them as much as you want and learn at your own pace. Also, I liked that the projects all looked at different elements of vehicle lighting."
    - "The real projects were nice. I appreciated having almost free reign with certain design specifications that needed to be met. I liked how the lessons were set up with different parts and questions at the end."
    - "Overall it's a cool class. I enjoyed learning the new software and it was enjoyable to design headlights that actually worked."
    - "I think that this class is definitely one that can be offered as online or hybrid in the future. Even if this class is offered as in in-person class, I think students will certainly benefit from having the lectures recorded."
    - "Even if you aren't necessarily looking to go into the automotive lighting industry, this course still gives you valuable experience with the optical design process. You will create reflectors, refractors, housings, choose LEDs, and tolerance your designs just to name a few things."

- Describe one or more ways this course can be improved.
    - "Either learn how to use Solidworks, or teach everyone Rhino."
    - "I think the only way to really improve it is by making sure the course stays on schedule."
    - "I think it could have been interesting to do a team project."
    - "I wish there would have been time to look at more functions."
    - "It'd be nice if we could learn a little bit more about the LED's themselves and how they are designed."
    - "It would have been neat to create a headlight housing, and show it along with all of the other lights on a 3D model of a vehicle."
    - "As an actual criticism, I think some basic 3D modeling tutorials would help a great deal, as this was actually my first experience with CAD software."

As pointed out by one student, the options for CAD tool turned out to be an issue. To improve the course in the future offerings, there are two new options: 1) only use Rhino, 2) use the new version of Lucidshape with integrated CATIA as the CAD tool. Regarding the issue on schedule, the circumstances with COVID-19 had caused one extra week of the classes to be eliminated in preparations for the pandemic and that one week had a negative effect on the course schedule. Another item that delayed parts of the course was the need to move online and record the lectures, during which occasional technical difficulties led to re-recording a few of the lectures and causing delays. In a normal schedule, such problems would not be an issue. The suggestion for team projects is interesting and would be investigated at a later time. Some of the feedback for improving the course really needs more time for the course, more than the available 10 weeks, which indicates the desire of students to learn more in courses like this.

### 3.6 Future developments

Future topics being considered to be added include:

- Discussion on Etendue: definition, conservation of etendue, skewness, measurements and standards.
- Lighting Business: Markets and business structure. Utilities, Lighting regulations. Evolving business models for lighting.
- Vision factors and visibility levels, contrast sensitivity; color vision; accommodation, adaptation, brightness and lightness.
- Practicing Failure Mode and Effect Analysis (FMEA) for the designed lamps.
- LucidDrive is an amazing addition to Lucidshape in which students can virtually drive a vehicle on a selected road with the headlamps they have designed.

### 3.7 ABET

Since the Optical Engineering program at Rose-Hulman Institute of Technology is ABET accredited, it is important to review the Criterion 3 for Student Outcomes [9]. According to the definition, student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the knowledge, skills, and behaviors that students acquire as they progress through the program. The Student outcomes in the new definition are outcomes (1) through (7) below:

1) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2) an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3) an ability to communicate effectively with a range of audiences

4) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6) an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7) an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

The developed course on automotive lighting primarily addresses ABET student outcomes 1-4 as listed above.

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