2017 ASEE Mid Atlantic Section
Spring Conference: Morgan State University, Baltimore, Maryland Apr 7 Paper ID #20826

Illuminated Umbrella: An Engineering/Visual Arts Interdisciplinary Product Development

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Illuminated Umbrella – An Engineering/Visual Arts Interdisciplinary Product Development

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The Raritan Valley Community College (RVCC) Engineering program "Authentic Engineering Experience" course tasked a Team of four Engineering students to design, prototype, build, and deliver a real product to a real customer. The product, designed in collaboration with RVCC Visual Arts students, was an umbrella that illuminated 200 LED lights when opened – without the use of batteries. The objective of the course was to expose students early in their academic careers and under "authentic engineering" conditions, to vital skills and practices used daily in industry. A secondary goal was to give students product development and project execution experience to relate to potential internship and professional employers.

I. Introduction

An Engineering & Visual Arts collaboration in Fall 2016 resulted in a unique Illuminated Umbrella product where a transparent plastic umbrella, sequined with 200 LED lights along the umbrella ribs, illuminated when opened – but required no batteries. The Engineering Student Team consisted of four 2nd-year Raritan Valley Community College (RVCC) Engineering students participating in an “Authentic Engineering Experience” course where they were tasked to design, prototype, build, and deliver a real product to a real customer. The Visual Art Student Team, comprised of ten RVCC Visual Communications majors enrolled in the Fall 2016 Visual Design 2 course, were each tasked with developing a complete graphic-identity for the product including a unique product name, a logo, corporate collateral (business card, envelope, letterhead), product packaging, and two print advertisements.

The Illuminated Umbrella product required the Engineering Student Team to learn, hands-on, how to generate the required electrical energy using the physics and engineering principles of electromagnetic-induction, store the energy in capacitors, and release the energy to the array of LED lights. The Engineering Team presented prototypes to the “Customer” (Visual Arts Professor and co-author McManus) and the Visual Design 2 students and responded to their feedback to configure the umbrella components to create a more contemporary aesthetic.

The Visual Design 2 students worked collaboratively as a class to generate ideas to improve the overall design and functionality of the Illuminated Umbrella and were each individually tasked to develop a unique graphic-identity for the product as well. The design concept for each graphic-identity was based on the envisioned target market for the product, which varied from student to student. The actual design execution was predicated on ease of product recognition using the product name and logo, selected color palette, supplementary graphics and typography, and uniqueness of the packaging solution intended for distribution and sale.

This project was a genuine inter-disciplinary Engineering and Arts collaboration. The Illuminated Umbrella product and the three best graphic-identities were featured in the RVCC Art Gallery as part of the Independent Study Students Exhibition from January 23rd to February 10th, 2017.

The motivation and goal of the project was to expose the Engineering Team early in their academic careers and under "authentic engineering" conditions, to vital skills and practices used daily in industry. The practical objective was to give students authentic hands-on product development and project execution experience to relate to potential internship and professional employers. Although guided at arms-length by industry-experienced staff, the overwhelming emphasis was for the Engineering Team to reach their own designs, experience their own failures and successes in earning their own know-how, resolve their own communications and scheduling conflicts, and to respond to customer critical comments of prototype product performance.

The spirit of this project is in line with previous successful efforts to expose students to "authentic" engineering experiences and environments through, for example, Service Learning [1], Learning Factories [2], Capstone Projects [3], hands-on 1st-Year Engineering Courses, Learning in Laboratory Settings [4], and Engineering courses featuring Mechanical Dissection as a learning tool [5].

The current "Illuminated Umbrella" project is a continuation of the pilot "Authentic Engineering Experience" course initiated at RVCC in 2015 [6] and is one of two projects presented at this conference [7].

II. Industry Skills Focus:

During the project the student-professor relationship was suspended and replaced by a professional engineering team – manager relationship. The scenario was that the student team were employees of an engineering company that makes novel technical products for specific customers. All project activity was hands-on and "live" – without classroom lectures or Labs. Principles and skills were experienced first-hand. The focus was for the student team to learn by doing. Concepts and skills emphasized were those directly useful for engineers in a professional/industry environment and included:

- Focus on the Customer - Communicate with the customer, understand the customer's needs, and negotiate achievable needs, conduct interim demonstrations, collaborate with the customer, and deliver the product on-time.
- "Do what you say you will do" – Teamwork, division of labor, project planning, task execution, leadership, and responsibility.
- Engineering Prototyping – Idea generation, start simple then improve, face high-risk problems first, think through each step in-detail to reduce risk
- Grit and Determination – Anything that can go wrong will go wrong – push through.

III. Voice-of-the-Customer

The Engineering Team consisted of four RVCC second-year engineering students. The Team was not informed of any of the details of the project – not even the type of product to be made. The project started on the first day of the semester, September 2, 2016, with a meeting with the Customer to learn the details of the product request and specifications.

The Customer requested an illuminated umbrella to light the users path when the umbrella was employed during the night-time. The customer's concept was that the umbrella was a transparent plastic umbrella that illuminated 200 LED lights when opened but required no batteries and that the LEDs remained lit for at least 60 seconds. The customer did not indicate or suggest how to achieve the required product performance – those decisions were left entirely to the student Team.

IV. Idea Generation and Exploration

In response, the Engineering Team conducted a brainstorming session to generate ideas to address the Customer's requested product. The brainstorming used standard rules where each team-member sequentially gave one idea and where all ideas were listed without discussion or critique. The idea was to generate as many specific and open-ended ideas as possible. The result was a large list of ideas that covered a broad spectrum of possible technologies and solutions. The Engineering Team recognized that they needed to learn more about many of the ideas before decisions could be made as to which sub-set of technologies or approaches would likely be the more effective. The ideas were roughly grouped into categories that would later form the main areas of engineering work for executing the project, including power generation, energy storage, electrical circuit, and mechanical assembly and waterproofing. The Engineering Team members each accepted to research a set of the brainstorm ideas. At the next meeting the team-members reported back using 3-5 minute presentations per key topic to efficiently inform the Team with the objective to reduce the technology options to a few testable technologies.

The Engineering Team was then encouraged to hands-on test and evaluate the technologies that they determined to be most likely to be successful for the project. Technologies tested for the Illuminated Umbrella project were: 1) battery-less energy generation including, electromagnetic induction, piezoelectric, thermoelectric, and solar, 2) LED products including, 5mm low voltage (3V), high power (1W), and 12V Led Strip lights, 3) energy storage including parallel and series super-capacitors, and 4) electrical energy delivery circuits including RC-circuits and DC-DC converters.

V. Technology Selection and Prototyping - 1st Customer Demonstration

After two weeks of hands-on testing, data collection, and evaluation, the Engineering Team decided that the Illuminated Umbrella product would generate energy by electromagnetic induction that would be stored in super-capacitors, released through a RC-circuit, to strings of hand-soldered 5mm low voltage LED lights.

The Engineering Team members divided the responsibility to focus on the main technology areas to make progress in parallel. Co-authors Romero and Sitarz focused on electromagnetic energy generation, Skibik developed the electrical energy storage and delivery circuit, and Smith was responsible for developing the method to assemble, attach, and water-proof the LED lights to the umbrella and defined the wire management.

An initial project plan was developed to coordinate the Team's work tasks. A Team Leader was chosen from the Engineering Team members on a weekly basis to maintain the schedule, communicate within the Team to ensure all members stayed on schedule, identify technical and schedule problems during the week, and maintain and communicate a parts-order list. The Engineering Team and the "company" manager (co-author Stupak) met a minimum of once per week to review progress. The Engineering Team members were expected to invest at least six professional-engineering hours towards the project weekly. The first Customer prototype demonstration meeting was defined for October 25, 2016.

VI. Electromagnetic Induction Power Supply

Tasked with generating the energy to illuminate 200 LEDs for 60 seconds, the team reverse-engineered several commercially available no-battery products which employed user-power generation. The products included a large shake-powered flash light, a small hand-crank camping flashlight attached to a DC motor, and a small induction pull-cord flashlight. Each of these products were carefully disassembled and important characteristics of each product were measured, tested, and calculated, including the principle of operation, dimensions, voltage and current as a function of operation rate.

The team concluded that the small pull-cord induction flashlight produced the most electrical power. The pull-cord flashlight principle of operation consisted of an arrangement of metal prongs on the top and bottom on a copper coil oriented the same way, with a toroidal magnet rotating above the arrangement. In addition, there was a reducing gear-train that increased the rotational rate of the of the magnet relative to the pull rate of the cord.

Once the team gained enough of an understanding of the mechanisms that allowed this product to work well, they manufactured their own coils and metal prongs to scale the mechanism for use to power the 200 LED lights. Coils of varying diameters, heights, and wire gauge were made to explore the design space and performance. An electric hand-drill was used to wind the coils from a spool of enamel coated copper magnet-wire. The metal prongs were cut out of 1/16" sheet steel using sheet-metal shears and hand-fit to the coils. The magnet arrangement in the commercial product was reproduced by cutting disks out of a pressed paper-board material and drilling holes symmetrically around the circumference into which strong ¼" diameter Neo-Rare Earth cylindrical magnets were inserted.

Although successful in making the prototypes function and generate electrical energy, ultimately the team was not successful to reproduce the commercial product performance or to scale the device output. Part of the problem was an incomplete understanding of the commercial device function, but the main reason was mechanical in that the resources were not available to the Engineering Team to properly align and mechanically hold the prototype parts along a precision axis. The defeat was not without considerable effort as the Team made dozens of coils amounting to more than five miles of copper magnet-wire memorialized as the "ball of knowledge" as a sobering reminder that what seems trivial in principle is very much more difficult in practice.

The Engineering Team decided to instead use a DC motor attached to a reducing gear-train that would generate electrical energy by electromagnetic induction when rotated mechanically by the Illuminated Umbrella user. Several motor sizes/weights, voltage ratings, current outputs, and gear reductions were tested. The choice was a 24v, 0.5A output at 100rpm, 40:1 Uxcell DC motor. A handle attached to the motor shaft generated enough torque to allow the user to turn the motor easily to generate the electrical energy (Fig. 1).

Figure 1. A second iteration of the "Illuminated Umbrella" power supply showing the DC motor attached to the umbrella axial runner and hand crank mechanism.

VII. Electrical Storage and Delivery Circuit

Once generated, the electrical energy needed to be stored temporarily and released in a controlled manner to illuminate the 200 LED lights at high-brightness for at least 60 seconds. Most of the Engineering Team had little background in circuit elements and the electrical principles needed to properly construct the circuit. Much of the learning resulted from hands-on experiments and the applied knowledge of some Team members who learned the principles of electromagnetism in Physics class. Calculations were performed to determine the amount of energy that needed to be stored. Experiments were conducted to charge and discharge capacitors of different capacitance and voltage, test RC-circuits with different resistors to vary the circuit discharge time-constant, and evaluate DC-DC voltage converters to power the LED lights. A 200-LED parallel-circuit test-bed was made to directly test the different circuits under the real power requirement of the final product (Fig. 2).

The Engineering Team decision was to use a RC-circuit consisting of low-voltage (5.5V) and 1/3 Farad capacitors in parallel and an 18 Ohm resistor. The selection of the capacitor was initially difficult because capacitors of higher voltage to store energy at a higher potential were both physically too large and too expensive while the lower voltage capacitors surprisingly exhibited an internal resistance upon discharge that required an unexpectedly small value for the resistor in the circuit. The low voltage capacitors were inexpensive, physically less than 10 millimeters in diameter and 5 millimeters thick, with high capacitance at 1/3 Farad, and were easy to solder into a parallel configuration.

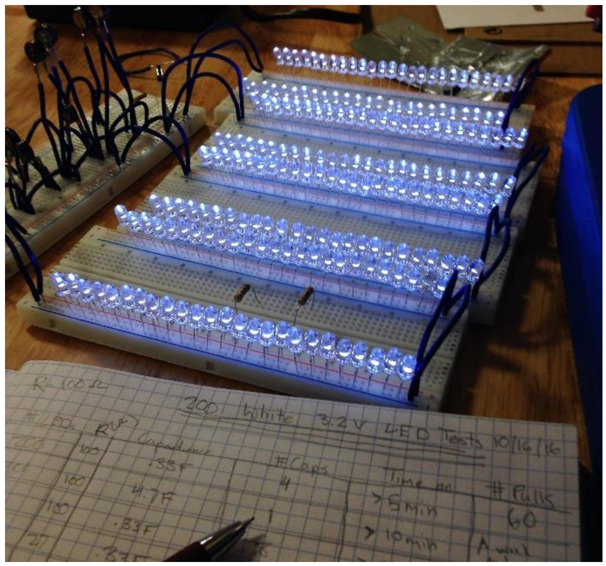

Figure 2. The 200 LED light test bed used to directly measure the electrical energy storage and release effectiveness of the capacitor-resistor (RC-Circuit) and capacitor-DC/DC converter circuits. In this case the full number of LEDs used in the final product were able to be conveniently tested at low cost.

VIII. Mechanical Assembly

The 200 LEDs required by the Illuminated Umbrella product were positioned radially in strings of 25 LED lights along the 8 ribs of the umbrella. Each string of 25 LEDs was a parallel circuit and made by inserting the LEDs into a jig to pre-set the distance between lights. The conductive wire leads of the LEDs were attached to an uninsulated single-conductor wire and soldered in place and remaining lead cut off. The completed string was carefully pulled through a 1/2" ID and 3/4" OD transparent plastic tube that was used as a mechanical support and later as a waterproof housing.

The mechanical assembly and placement of the LED lights turned out to be equivalently difficult in terms of sheer effort and difficulty as the effort to make the power supply. The assembly of the LED strings was tedious, the solder joint between the leads was small and weak, and when pulling the LED string through the plastic tubing the remains of the LED conductive wire leads would often catch on the tubing inner surface resulting in the wire breaking. Additionally, the repeated local flexing of the LED leads and attachment wire near the solder joint resulted in work-hardening and fracture of the wire. The work hardening and weak solder joints were decreased significantly by wrapping the wire around the entire lead and orienting the leads to all be in one direction following each LED. This added extra support from the increase in wrapped wire and in the amount of soldered used, while maintaining similar levels of flexibility and reducing work hardening. The Engineering Team overcame these issues by applying determination and grit and following one all-night marathon-assembly effort, the Team members announced that in fact, "everything that can go wrong, does go wrong!". Also, the 25-LED strings were attached to the umbrella ribs using transparent zip-ties. Clear adhesives were also attempted but were not successful solutions.

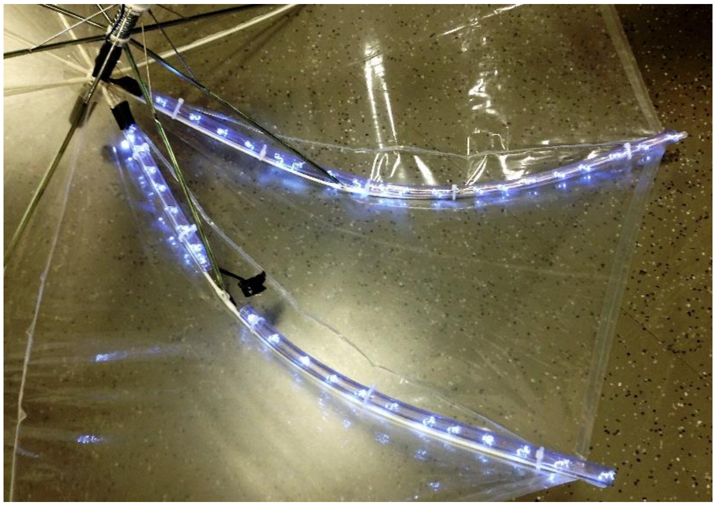

Figure 3. A prototype version of two LED light strings with the LEDs soldered into a parallel circuit and inserted into colored plastic tubing. The tubing is attached to the umbrella ribs by clear zip-ties.

IX. Customer Demonstration

The Engineering Team presented the Illuminated Umbrella prototype to the Customer and the Graphic Design 2 students during the Graphic Design class on October 25, 2016 – about 7 weeks from the project start (Fig. 4). The Engineering Team explained each part of the product function and demonstrated the product. At that time, only three of the eight umbrella ribs had LED lights attached, the DC motor was exposed and with a make-shift rotating-handle, the capacitor circuit was assembled on a circuit board and crudely attached to the umbrella handle, and loose wires along the main umbrella central shaft connected the motor and circuit to the LED lights. The umbrella illuminated on the first attempt to the delight of the customer and students. But a second illumination attempt failed due to wire breakage. The repeated opening and closing of the umbrella caused local flexing of the single-conductor wires connecting the LED strings at the apex of the umbrella leading to work hardening of the wire and inopportune fracture and failure in front of the customer.

Figure 4. Second Customer demonstration November 21, 2016. Upper left photo showing RVCC Engineering Team members and co-authors, E. Smith, M. Romero, and J. Sitarz (left to right) presenting the Illuminated Umbrella prototype to the Visual Arts Graphic Design 2 students. Upper right-photo showing collaborative discussions of the Illuminated Umbrella design between the Engineering and Visual Arts Teams. Lower photo showing the Illuminated Umbrella in use.

The collaboration between the Engineering Team, the Customer, and the Visual Arts Team students was remarkably productive. Conversation flowed freely between the Teams. The Visual Arts Team requested that the umbrella handle remain without any attachments to not interfere with the existing elegant shape. Their suggestion was to relocate the motor and the circuit onto the mechanical umbrella “runner” component that holds the lever-arms for the umbrella ribs and slides on the central umbrella shaft. The Visual Arts Team also suggested that the motor handle be replaced by a more compact and elegant wheel – also effective at delivering the required torque and that the plastic tubing encasing the LEDs remain clear and the LEDs emit blue light (Fig. 5). The one request that was not possible for the Engineering Team to complete was the possibility to use LED strings of different color. Each LED color requires a different voltage and the circuit required to distribute the correct voltage to each colored string was not able to be made successfully. The work-hardening problem was resolved by using multi-strand conductor wire with strain-relief loops.

The collaboration of the Engineering and Visual Arts Teams resulted in a much better functioning and appearing product than would have been possible had the Engineering Team only worked to the original customer specifications. The product changes placed the team in situations where they needed to reject well thought-out existing ideas, develop new creative solutions, and/or guide the customer towards more technically feasible alternatives. This customer to engineer collaboration provided the team with the opportunity to satisfy the customer and address technical difficulties with an audience unfamiliar with the engineering aspect of product design.

Figure 5. The final design arrangement of the "Illuminated Umbrella" DC-motor power-supply attached to the umbrella central runner, parallel circuit of 1/3 Farad capacitors (i.e., ring of dime-sized components around central shaft), and hand-wheel that replaced hand-crank. The clear plastic tubing containing the LED lights and zip-tied to the umbrella ribs is also visible in the background.

The Visual Arts Team members were tasked individually to develop a unique graphic-identity for the product as well. The design concept for each graphic-identity was based on the envisioned target market for the product, which varied from student to student. The actual design execution was predicated on ease of product recognition using the product name and logo, selected color palette, supplementary graphics and typography, and uniqueness of the packaging solution intended for distribution and sale (Fig. 6).

Figure 6. The top three "Graphic Identities" developed by the Visual Arts students from the Graphic Design 2 course. Each unique graphic-identity for the product was based on the envisioned target market for the product and on the ease of product recognition using the product name and logo. The graphic identities, clockwise from the upper left, are Ohmbrella (J. Jannone), Amp Shade (N. Vuolde), and Umbrellights (Matt Zgorzynski).

X. Final Product Delivery and Art Exhibit

A second customer demonstration was given November 21 and the final customer demonstration and product delivery was conducted December 19 (Fig 7). During the intervening period the Engineering Team devised solutions to incorporate the product improvements suggested by the Visual Arts Team.

Additionally, a 3D-printed case was developed to cover the DC motor and capacitor circuit. Autodesk Inventor 3D-modelling software and a Makerbot 5th Generation printer was used to design and fabricate the case. Precise measurements were needed to create a case large enough to fit all the components but small enough to be comfortable and fit within the umbrella. One of the difficulties encountered when designing the case was that the design was too detailed from the start. This led to the case being too small and not quite the correct shape to completely fit the motor and circuit. Simplifying the design ended up being the solution to this problem and resulted in a valuable lesson - to start simple when designing.

During the final meeting the Engineering Team was asked to judge the individual product graphic-identities created by each Visual Arts Team member to identify the top three. The creativity and broad ability of the Visual Arts students made judging difficult as all designs were impressive. The top three designs were created by co-authors: Nick Vuolde (Amp Shade), John Jannone (Ohmbrella), and Matt Zgorzynski (Umbrellights).

After the delivery of the product to the customer, the Engineering Team and top-three Visual Arts Team members team presented the Illuminated Umbrella and graphic identities to the public at the 2017 Independent Study Student's Exhibition in the RVCC Art Gallery. The interaction of the Teams with the public through the exhibition's Artists' Talk gave all team members the opportunity to show and explain their work. The presentation together by both the Engineering and Visual Arts students emphasized the collaboration between the engineering and visual design disciplines. As the engineering students presented a technical breakdown of the umbrella and how it worked, the design students explained how that knowledge, and other outside sources inspired their clever ideas for brand names, logos, and designs.

XI. Assessment and Conclusion:

The Engineering Team did not maintain a time log for the project, but a safe estimate would be a combined 300 hours spent researching, building, and testing the umbrella. This project was open-ended with no clear-cut solution, mirroring the same type of problem that professional engineers are faced with every day.

The assessment of the project success was viewed from two perspectives. The first was that the RVCC student Engineering Team delivered a fully-functioning product that met or exceeded the Customer specifications and expectations. This was a significant achievement given the challenging and open-ended problem, the Team's initial knowledge level, and the brief execution period. The second was that the responsibility of designing and delivering a real product to a real customer, and under authentic engineering conditions, was effective in accelerating student learning of important skills that are often acquired later when employed in Industry. The concepts of focusing on the Customer, doing what you say you will do, aggressive prototyping, and determination and grit, became real.

The result was a mature, cohesive, open-minded, and effective student Team that delighted their customer.

Figure 7. The final presentation of the "Illuminated Umbrella" project to the Customer and Visual Arts students. Left photo showing the Illuminated Umbrella in use and the 3D-Printed case surrounding the motor and circuit. Right photo showing the Illuminated Umbrella at the Art Exhibit.

Acknowledgements:

The Authors want to thank Melissa Ignacio for originating the idea for the "Illuminated Umbrella" and her efforts and contributions to help initiate the project.

Additionally, the authors would like to recognize the other seven students in the Visual Design 2 class who, although not selected for inclusion in the Independent Study Student's Exhibition, did complete visual identities and package designs for the project and added valuable feedback during Team meetings: Evan Ardanaz, Angel Juarez, Jamie Liu, Jackson Magnaye, Matthew Perrotti, Francesca Robinson, and Alessandra Sardella.

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