Construction and Characterization of an Inexpensive Electrostatic Lifter

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Abstract

The teaching of instrumental methods of analysis as applied to chemical and forensic science problems at many educational establishments continues to be hampered by high-cost, high-power requirements, and sheer bulk of the instrumentation. The SMILE initiative (small, mobile instruments for laboratory enhancement) that we have developed incorporates an inquiry-based project that addresses these issues by significantly engaging students, and thus enhancing the confidence and achievement of students in our technology-based analytical courses. One instrument that has been designed, constructed, and characterized is the electrostatic lifter. The electrostatic lifter is a versatile nondestructive technique that can lift and recover impressions of prints left in the dust of a floor, and from dusty walls or doors. The instrument and technique conveniently lends itself to miniaturization, and facilitates the practical application of impression analysis within standard undergraduate and advanced high school forensic science related courses. The entire instrument was constructed from scratch for less than $50, thus allowing deployment of multiple apparatuses in labs that are allocated a modest budget. Details on how to construct the instrument is provided together with some characterization data obtained from a variety of smooth and rough surfaces.

Keywords
Keywords (Audience): **Upper-Division Undergraduate, First-Year Undergraduate/General**
Keywords (Domain): **Analytical Chemistry**
Keywords (Pedagogy): **Hands-On Learning/Manipulative, Inquiry-Based / Discovery Learning**
Keywords (Topics): **Forensic Chemistry, Instrumental Methods**

Introduction

Analytical chemistry occupies a prominent place among scientific and engineering disciplines. It is a highly practical hands-on based scientific discipline with deep roots in the world of atoms, molecules, and molecular transformations, with the ability to precisely and accurately assess these entities with specific instrumentation. Analytical chemistry has evolved dramatically over the past few decades, from a collection of empirical recipes and prescriptions to that of a branch of chemistry built upon solid theoretical principles. The modern day discipline takes a more holistic approach to analytical properties; it is technology driven, and is research-active. The application of this field helps ensure quality of air, water, food, consumer products, and medicines. The application of this field ensures quality of air, water, food, consumer products, and medicines. Furthermore, the role of analytical chemistry in solving crimes, both to protect the public and to protect the innocent from unjust punishment cannot be overstated. Applications in forensic chemistry have served as a rich palette from which we have been able to stimulate the interests and abilities of students, particularly those that arrive from non-major chemistry/forensic science fields.

An understanding of the scientific process in selecting the right tools, and the technologies involved in such instrumentation has been an important goal of the analytical chemistry courses developed at Penn State over the past two decades: Our analytical chemistry students learn to appreciate the many quantitative and qualitative tools available, and most importantly, make an intelligent choice among the many possible ways of solving an analytical problem. We purposefully place a strong emphasis on students acquiring a deep insight into the principles upon which the methodology is based, thus ensuring proper use and a learned evaluation of the experimental findings. This approach leads to a thorough understanding of the scientific process that can be applied to many other problems and disciplines, including forensics. One inquiry-based module of these courses is centered on development of small inexpensive analytical instruments that we have abbreviated as SMILE (Small, Mobile Instruments for Laboratory Enhancement). This lab pedagogy requires students in the upper level instrumental analysis course to research into, design, construct, characterize, and troubleshoot small instruments. The process guides the students in asking relevant research questions regarding the required materials and techniques, and includes background information and training protocols that are necessary to achieve the overall objective which is a well-designed functional analytical instrument (1-8). Underclassmen, including visiting school students, are then taught how to assemble the instruments from kit form, and how to make full use of them upon returning to their classrooms.

The instrument described herein augments instruction relating to impression evidence, specifically to the application of an electrostatic dust print lifter, a versatile technique that can lift and recover impressions of prints left in the dust of a floor, in light soil from a criminal's shoes, and from dusty walls or doors (9-12). Locating and recovering obvious impressions from mud, dirt or blood are common and easily accomplished, but dust prints found in many indoor crime scenes are often overlooked and damaged or obliterated, and therefore a sensitive lifter instrument is indispensable in gathering physical evidence. Using footwear marks to track movements of suspects can lead to other forms of evidence, and so assist in placing other collected evidence into context and thus ensure a full scene investigation takes place. The entire electrostatic lifter can be designed from anywhere between $50 to $75 depending on if the instrument is designed from scratch or if a driver plus multiplier is purchased to aid in its construction. This is clearly an inexpensive alternative to commercial lifting devices that can cost upwards of $650 or more. The instrument remains under constant development, and our latest model has obtained some remarkable data from a variety of smooth and rough surfaces.

Methodology

Three commonly used methods for lifting dust shoeprints are electrostatic lifters, gelatin lifters, and an adhesive lifter followed by chemical enhancement. The electrostatic lifter is a nondestructive recovery process, and operates by applying a high voltage electrostatic charge onto a lifting film which is placed over the imprint mark. A metal plate to the side serves as the reference ground. The resulting charge difference between lifting film and the surface on which it rests causes dust on the surface to attach to the film, this adhesion draws the film onto the surface bearing the print. The film retains a charge after the unit is turned off, and so retains the particles of dust. Such commercial devices are capable of producing a charge in the range of 10 to 15 kilovolts, however the current is negligible. The lifting film is metalized Mylar foil (part no. A-5036, Arrowhead Forensics, Lenexa, KS). One side of the foil consists of a conductive material which holds the electrostatic charge. The other side of the foil consists of nonconductive material and is the side which captures the attracted dust particles. Figure 1 shows the constructed lifter device.

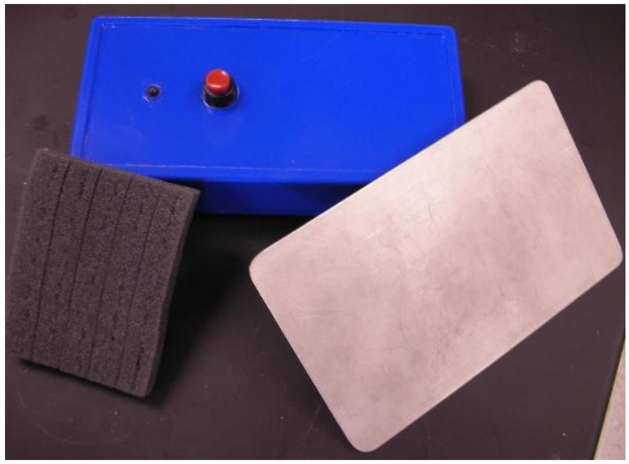

Figure 1 The electrostatic lifting device constructed by students (blue), together with the grounding plate and Mylar lifting film.

The electrostatic lifter is powered with a 9 V alkaline battery, and features a Cockcroft-Walton multiplier which allows generation of a high voltage at very low current. The voltage output of the lifter is between 10 to 12 kV. The circuit is completed when metal grounds touch the stainless steel plate and the voltage output lead is connected to the lifting film. The circuit diagram is provided in Figure 2. A detailed list of components and a description of the circuit are provided in the Supplemental Information (SI**)**. In order to build the instrument as shown, some machine work (drill press or hand-held drill) on the housing is required, which may add a very small cost that is not reflected in the total. Figure 3 shows the internal layout for the electrostatic lifter which uses an in-house etched breadboard for the transformer and other circuit components; however, the simplicity of the design permits direct solder connections between the components. The Cockcroft-Walton multiplier was purchased fully assembled from the manufacturer.

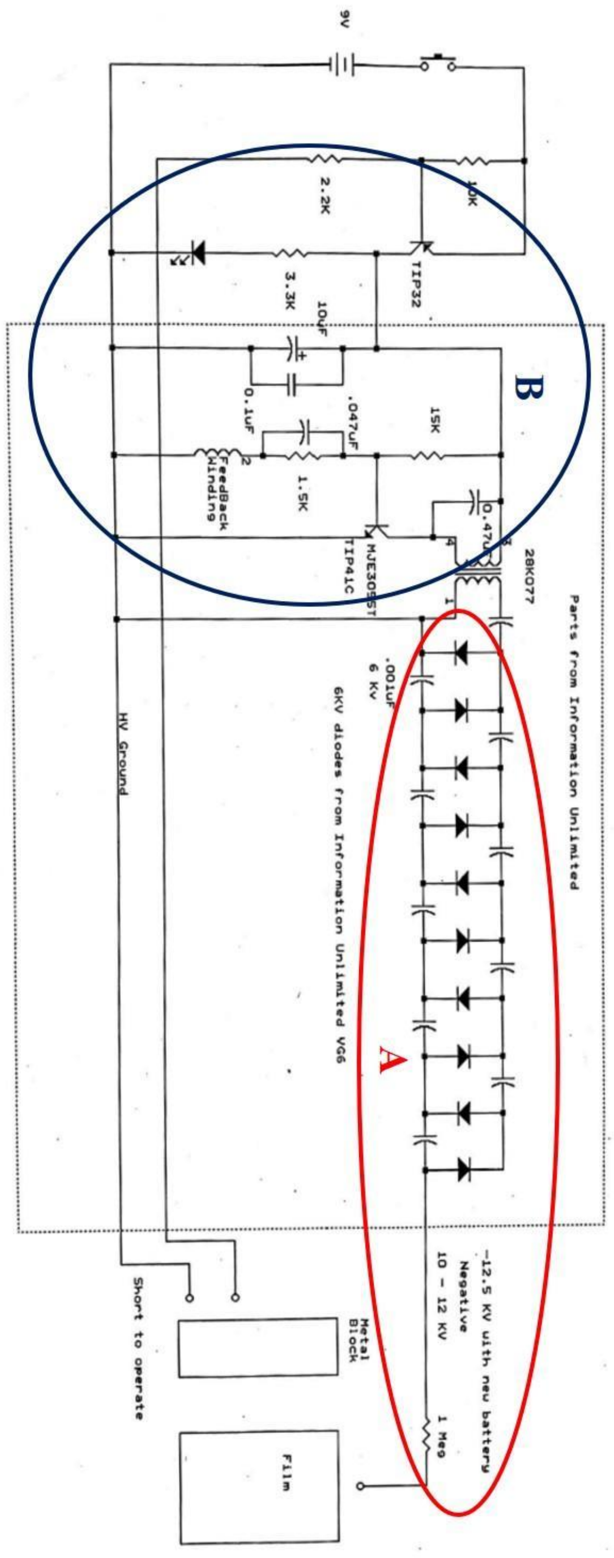

Figure 2 Circuit diagram for the electrostatic lifting device. A is the Cockcroft-Walton multiplier, and B is the driver circuit for the multiplier.

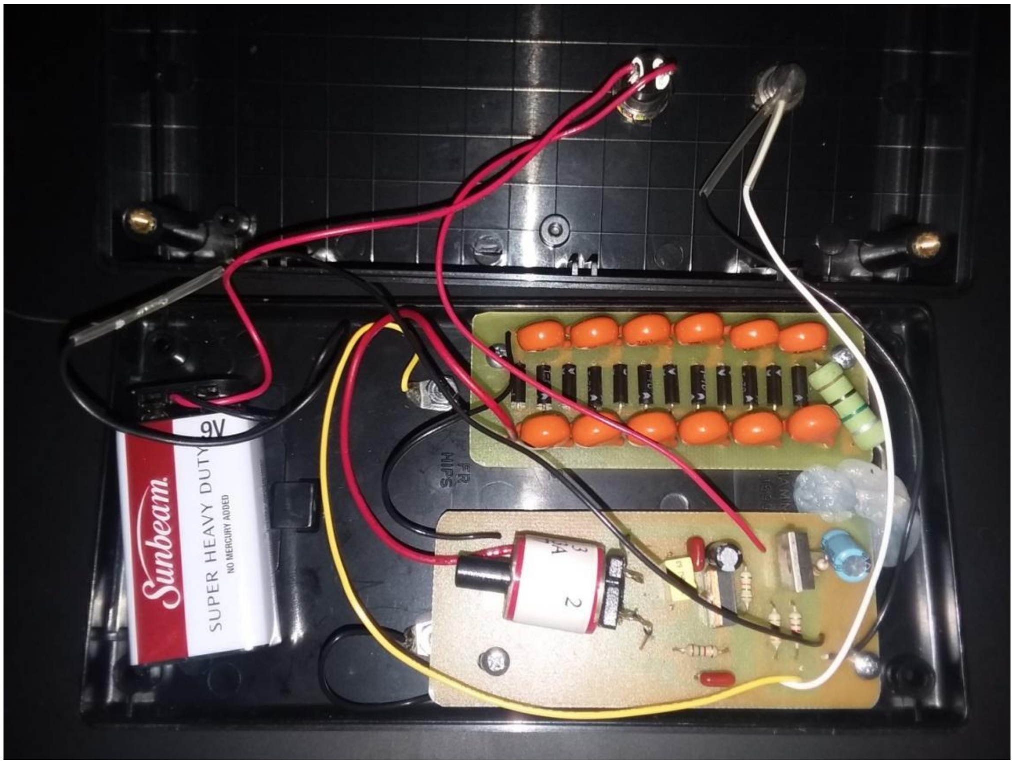

Figure 3 Internal bread board circuitry highlighting connections to the momentary on-off button and the LED located on the lid of the housing.

The electrostatic lifter takes less than two hours to construct from kit form. The assembled unit has dimensions of 17 cm x 8.5 cm x 3.4 cm. The decision to use a pre-assembled multiplier and miniature AC transformer results in a far lighter instrument than the commercial units. The biggest advantage of such a circuit is that the voltage across each stage of this cascade is equal to twice the peak input voltage into each respective stage, thus requiring relatively low-voltage-rated components.

Once assembled, students conducted a series of experiments based on published literature (12). The electrostatic lifter was tested on nine different surfaces including office paper, carpet, linoleum, ceramic tile, untreated cement, waxed-sealed cement, cardboard, newspaper, and hardwood flooring. Using a pair of rubber-soled sneakers, students identified up to ten individual characteristics of the right foot impression. A volunteer puts on both sneakers and, using the right foot, steps into some all-purpose flour, and then walks 20 paces on a given surface. Students then used the electrostatic lifter to lift the 11th step of the right foot and all subsequent steps until at least one of the individual characteristics (as identified earlier) drops out of a lifted print. The step at which this occurs depends on the type of surface, amongst a number of other factors. The specific choice of the 11th step came from an initial experiment which found prints from a smooth tiled surface provided a high-quality print up to the 13th step, and prints of rapidly diminishing quality following this step.

The lifting process and image acquisition were generated by carefully placing the lifting film over the surface of the impression. The grounding-connection plate was placed adjacent to the lifting film, and the lifting film was charged. The charge was distributed throughout the film using a foam brush. The film was then removed and viewed using white oblique light and photographed using a digital camera. The Mylar film used to collect the impression can attract excess dust, and so it was important to photograph the dust print lifts immediately. If a print was not obtained on the 11^{th} step then the process was repeated on each prior step of the right foot until a useable impression was obtained.

Results

The real success of the student-built electrostatic lifter was measured by lifting foot prints from multiple surfaces. For each surface examined the 11^{th} right footprint was analyzed. The results of the experiments are presented in Table 1, and the lifted prints, as observed and photographed under white light are provided in Figure 4; the unsuccessful print from untreated cement is not shown.

TABLE 1 - Data from the constructed electrostatic lifter showing the footprints detected.

	Surface	Lifted Step
1	Office Paper	11^{th}
2	Carpet	8^{th}
3	Linoleum	11^{th}
4	Tile	11^{th}
5	Untreated Cement	Unsuccessful
6	Waxed-Sealed Cement	11^{th}
7	Cardboard	11^{th}
8	Newspaper	11^{th}
9	Hardwood Flooring	11^{th}

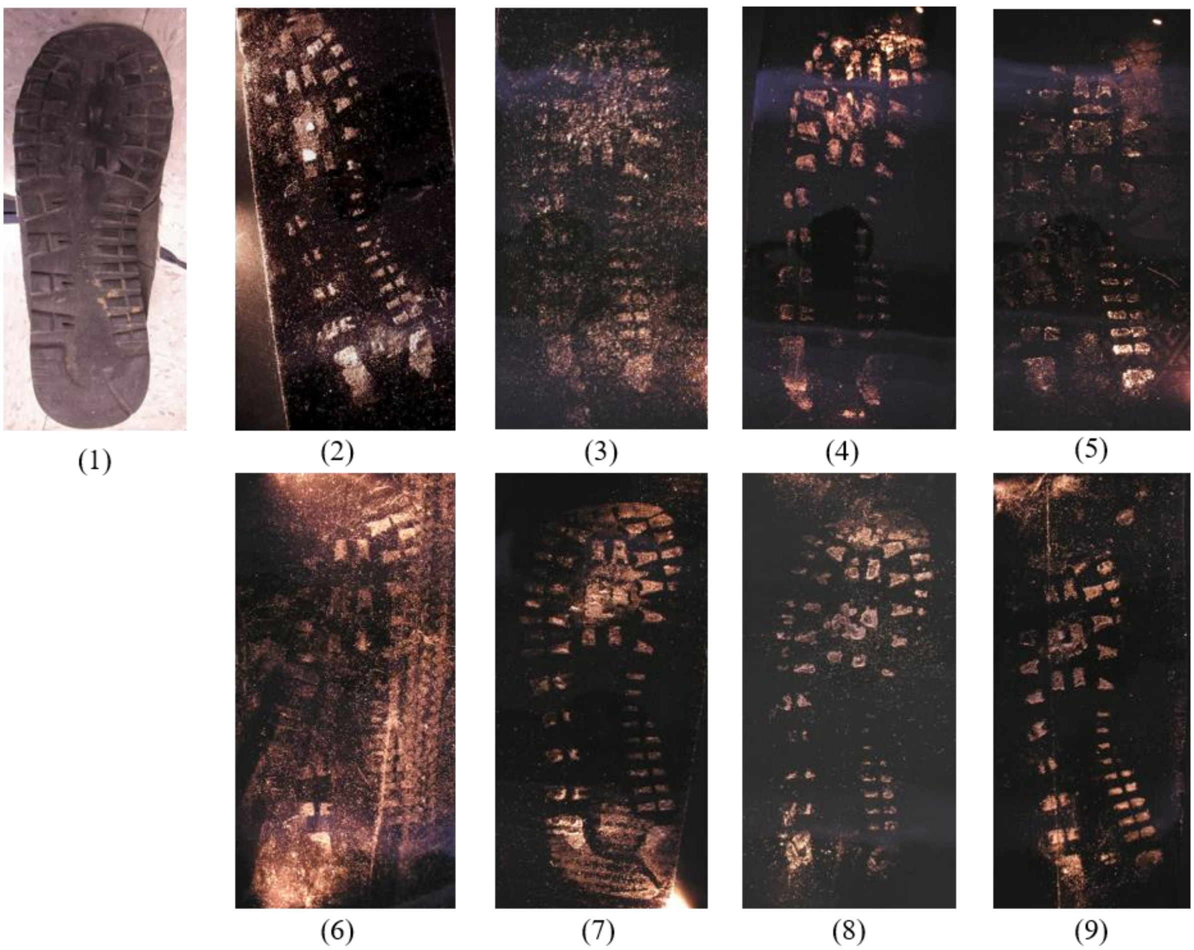

Figure 4 Photographed images of the lifted foot prints. (Top) The rubber sole shoe (**1**), carpet (**2**), linoleum (**3**), and tile (**4**). (Bottom) From waxed-sealed cement (**6**), cardboard (**7**), newspaper (**8**), and hardwood floor (**9**). Note that the lift is a mirror image of the actual impression.

Discussion and Conclusion

The specific student learning objectives (LOs) for the complete set of electrostatic lifter activities are as follows (After completing this module, you should be able to -):

1. Define and identify the class and individual characteristics of footwear impressions imaged using an electrostatic lifter.
2. Identify and explain the variables which impact the quality of the lifted prints.
3. Understand the theory of operation of the electrostatic lifter, and be able to independently operate, troubleshoot, fix, and maintain the device.

Students in the course have previously taken a course in crime scene investigation; therefore, LO #1 reinforces material already covered in the program's overall curriculum. LO #2 requires students to develop a method which isolates each variable in order to enable a discussion of the strengths and weaknesses of the electrostatic lifting device as an investigative tool. Variables, such as surface texture, humidity, pace, weight placed on each step, composition of sole material, wear and tear on sole surface, the thickness and distribution of flour on the sole of the footwear, among others, are commonly identified but not all student groups recognize such a 'complete' set of variables. Further, not all student groups perform the optimized method on a negative control for one or more of the surfaces. The students in the course are made aware that faculty guidance does not ensure a successful end to any project; success or failure is based on the student's initiative, motivation, organization, and work ethic.

The electrostatic lifter as constructed provides very good results on most of the surfaces that were investigated, with clear and distinguishable prints. The electrostatic lifter does require a smooth flat surface for best results, as determined by the quality of print and the failure to achieve prints from the untreated cement flooring. Because the surface of the cement is rough-textured, the Mylar lifting film does not adhere to the cement as effectively as the other surfaces, thus providing no recognizable results. Ideally, the dust film on the target substrate should consist of loose, very fine-grained, and dry dust for this process to work. The untreated cement was the only experiment conducted outside where humidity is of significant concern. The carpet surface was also less successful compared to other surfaces primarily due to its rough texture. The texture makes it difficult for a proper ground to be achieved when applying the electrical charge, and for the lifting film to fully adhere to the surface. Overall the other surfaces examined provided far better data due to the film fully adhering to the surface.

A student with sights set towards a career in the forensic sciences must possess a basic knowledge of the chemical and life sciences as well as have an advanced exposure to the tools and technologies used by these disciplines. By making tools accessible to students, they learn how to operate them and understand the capabilities and limitations of that particular instrument and methodology. Unfortunately, the ability of many programs and institutions to maintain and improve the quality of their educational offerings in this field is under constant threat because of the increasing costs to maintain state-of-the-art instructional facilities and the shrinking nature of funding sources.

However, it is possible to provide rugged, low-cost, low-maintenance, and low-power instruments capable of providing accurate information for a fraction of the cost of commercial instrumentation. The Small Mobile Instruments for Laboratory Enhancement (SMILE) program that we have developed has shown that it is possible, with just a basic understanding of electronics and instrument design theory, to obtain high-quality data from an instrument that students can build within a few hours (LO #3). The only substantial difference between a commercial instrument and a student-built instrument are the software and specialty components; the basic design and methods for probing chemical systems are practically identical.

At Penn State, students in the senior-level instrumental analysis and forensic chemistry courses build SMILE instruments as part of their laboratory experience, test their devices by performing standard experiments, and then assist in the development of new, unique laboratory activities and supporting instructional materials. The student-built instruments are then used by their younger peers in lower-level chemistry and forensic science courses. As the younger peers advance through the curriculum, they help improve the design of the instruments and help optimize the experimental protocols. The SMILE initiative enhances student competency in science and engineering fields, and the co-curricular exposure fosters student ownership of a program's curriculum. A number of the student-built electrostatic lifters have also been donated to Penn State University Police Services and to the US Postal Inspection Service.

The electrostatic lifter is relatively simple in design and construction, such that high school students, participating in a six-week summer research program sponsored by Summer Experience in the Eberly College of Science (SEECoS) in collaboration with Upward Bound Math and Science, have built and used the device.

The SEECoS program promotes educational opportunities for low-income students by helping them overcome class, social, and cultural barriers to higher education.

The design and construction of a small electrostatic lifter that can generate footprint data for forensic analysis at a fraction of the cost of a commercial instrument was described. The constructed electrostatic lifter is simple to use and has provided some high quality footprint results, particularly those that were lifted from smooth surfaces, as is usually found in an active indoor crime scene. The constructed instrument has additional merits of small size, low weight, and high portability since it requires just a single 9V alkaline battery. With some brief training, the electrostatic lifter device provides an effective and reproducible method for collecting and forensically examining latent dust footprints.

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