The Disassembly & Re-purposing of Unwanted Consumer Electronics: Low-Cost Materials for STEM Outreach

Laura B. Andre
Department of Electrical and Computer Engineering
University of Michigan
Ann Arbor, MI 48109
Email: lbandre@umich.edu

Timothy Jones
Outreach Coordinator
The Ann Arbor Section of the Optical Society of America
Ann Arbor, MI 48105
Email: trjones21@gmail.com

Abstract
During community outreach events conducted by collaborating optical societies in Southeast Michigan, interactions with pre-college educators indicated that the cost of materials and lack of knowledge or expertise prohibit many classroom activities involving science and technology education. In response, we began exploring whether discarded consumer electronics might be utilized for low-cost, hands-on STEM education and outreach. Point-and-shoot cameras and videocassette recorders (VCRs) are widely available and excellent sources for high quality optical and electromechanical parts but require disassembly. To test the project process and understand how to efficiently use all the components, we assisted students from second to sixth grade in disassembling cameras. Lenses, motors, and other functional scrap parts were harvested and reused to create something new. The activity encourages a process of inquiry, exploration, and tinkering, and deserves further investigation as an introduction to STEM topics. Our approach, safety precautions, and tips for disassembling cameras as well as VCR's are discussed.

1. Introduction

Concerns about K-12 science illiteracy has caused many professional technical and scientific organizations to expand pre-college educational programming and support for outreach activities. An example is the declaration of 2015 as the International Year of Light (IYL) by the United Nations. Related initiatives have been created to address broader issues regarding public awareness and perception of the process and benefits of science. As part of this call to action, the Optics Society at the University of Michigan (OSUM) and the Ann Arbor chapter of the Optical Society (AAOSA) conducted engagements at local schools and a variety of community events.[1] The successes, and struggles, of this outreach yielded valuable insight into some of the challenges facing K-12 science education in Michigan. The cost and preparation time for hands-on STEM activities and projects were frequently mentioned. Moreover, we believe that science and technology are best introduced and understood via an experience or through a process of inquiry, as opposed to a more traditional approach of presenting the facts and findings of science. The projects that our societies have developed aim to mitigate these problems that educators face and address the need for valuable, hands-on experience with STEM at a young age.

The goal of these types initiatives and programs is in general to inspire further learning and the pursuing of education in a STEM field. Despite this, research into project-based technical education has shown no difference in the success of undergraduate engineering students who were exposed to pre-college engineering outreach programs and those who were not.[2] Exposure to formal technology and pre-engineering classes was correlated to high self-efficacy scores, a predictor of future success in undergraduate engineering, while there was no measurable effect from multi-day engineering programs, school-related extracurricular engineering programs, and single-day workshops or field trips. However, informal personal experience with a technical hobby such as robotics, electronics, or programming was strongly associated with success and persistence in engineering students. This suggests that hands-on experiences, motivated learning, real-world applications, immediate feedback and problem-based projects are all common elements for these types of hobbies and can serve as guidance for future outreach activities.

For this project, we set out to create an outreach project that addresses teachers' cost concerns and technical needs as well as sparking a hobby-like interest in STEM through hands-on projects and promoting individual exploration. We see this project as having three phases: disassembling an item, examining its components and subsystems, and re-purposing the scrap parts to build something new. We have investigated and tested a method of structured disassembly of point-and-shoot cameras and by elementary-age students. The objective was to gain insight into the practicality of disassembly and reassembly activities. The activity also invites the opportunity for a discussion of electronic waste – what it is, why some things become obsolete, and what we do with unwanted items. Members of OSUM generously volunteered their time to assist in the execution of the project and were led by the authors who formulated the design and strategies for the project. Since this project is largely exploratory, collaborations with two after-school community programs served as a source for participants in order to determine its actual utility and impact as a classroom activity. The project gives young students a safe, hands-on opportunity for exploration and tinkering with technology as well as fosters an environment for motivated learning and real-world applications of STEM topics.

2. Materials and methods

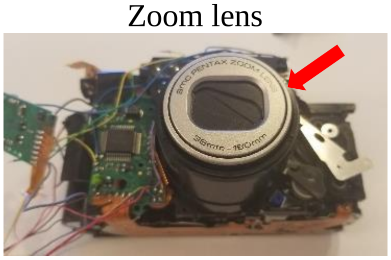
Cameras were collected from local resale shops and recycling centers. We noted that in general the heavier cameras had more valuable the parts inside. Before beginning disassembly, we asked students to think about what kind of parts and mechanisms will be inside based on what they perceive are the necessary functions of a camera. Batteries are removed before the exercise so that the capacitors will be completely discharged prior to disassembly. A precision screwdriver, Phillips #0001, is required to open the camera housing. A very small #00001 screwdriver is handy for a few of the internal parts. Volunteers are available to help the students loosen screws and separate parts as they tend to be tight or sometimes secured with glue. Safety glasses are required as small parts occasionally break off during disassembly. Each student is given a paper plate and a Ziploc bag to contain the parts.

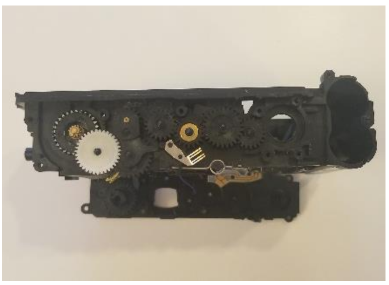
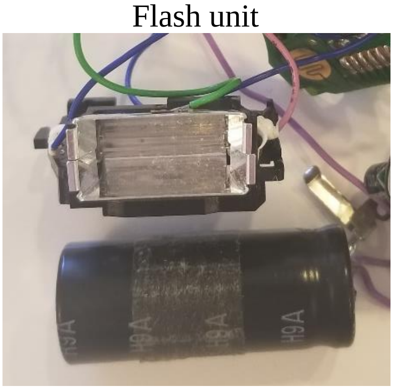
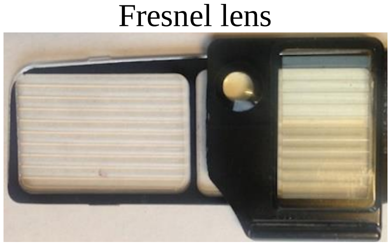
Once the housing of the camera is removed, it is important to confirm that the flash capacitor is discharged – making sure you that are using an insulated tool to short-out the large capacitor. The different subsystems of the camera can now be extracted. We point out specific parts that relate to the functionality the students previously described. Volunteers can explain the scientific principles behind the functions of each component, which can be tailored in complexity based on the perceived understanding of the age group. The students are encouraged to exact whole subsystems intact and to try to operate all mechanisms. A 3V battery pack is used to run one or more of the DC motors that may be visible at this stage – simply touch the bare wire leads to the motor terminals. A pair of wire cutters can be used to disconnect some the components – scissors also work just fine since the wires have relatively narrow gauge. Table 1 below summarizes the materials necessary to complete the disassembly phase of the project. We estimate that a single disassembly kit that would give one student everything they need to take apart a camera could cost as little as $10.

Materials	Quantity	Unit Price	Source
Camera	1	~$5	Electronics Recycle Center
Safety Glasses	1	$1	Home Depot
Phillips #0001 Screwdriver	1	$3	Home Depot
Wire Cutters (optional)	1	($6)	Home Depot
AA Battery Holder with Wire Leads	1	$1	DigiKey
	Total:	$10 ($16)	

Table 1: Materials and estimated total cost for one camera disassembly kit.

Next, the students study and tinker with the subsystems and the parts they found. Motors are operated, lenses are used to magnify, and gear mechanisms tested. As an exercise in reverse engineering, students are challenged to remove a part and then reattach it or completely disassemble a subsystem and then attempt to reassemble it. To make the process easier, we suggest bagging their other parts first and operating on a clean plate. Moreover, it is not necessary that the item be reassembled for the activity to be of value. A list of useful subsystems along with a description and project activity ideas can be found in Table 2 on the following pages.

Part	Description	Project Activity
Zoom lens 	A motor-driven telescoping mechanism containing multiple lenses, an iris, and a motorized focus. Here, the lens system is still attached to the exposed camera body in order to preserve and maximize functionality.	Use battery leads to power the telescoping of the lens, reversing the leads compresses the lens. Can be reverse engineered, make an alignment mark on lens tubes to ease reassembly.
Internal lenses 	Zoom lens contains several lenses in plastic retaining rings inside of tubular housing. Very high-quality magnifier.	Once removed from the zoom/focus mechanism, internal lenses can be examined by eye and used as a phone microscope or in a camera obscura project.

Part	Description	Project Activity
Viewfinder 	Has zooming capability and some are also focusable. Two single lenses are most common but may be configured as periscopes with mirrors or prisms.	Carefully extract unit keeping it intact as it can be operated by hand using attached control levers. Once functionality is examined, students are encouraged to disassemble and then attempt to reassemble the unit. Extracted lenses and prisms may also serve as useful parts.
Gear train 	Used to wind film, control lens tube extension, and other internal functions. Source for individual gears.	Care must be taken removing the plastic covering as the gears are not fixed in place. Once the cover is removed, gears can be turned to illustrate internal mechanics.
Flash unit 	Usually found in upper corner of camera housing. A large capacitor stores charge from a battery which produces a high voltage on the metal trigger plate behind the xenon gas tube when the flash is engaged.	A trained volunteer can carefully charge the large capacitor using the battery pack and demonstrate the flash for the student. Can also be used in a "static electricity detector" mentioned in Sec. 3 on re-purposing projects.
Fresnel lens 	Found in front of flash unit and glued to camera body. It concentrates and evenly disperses the light from the flash in the forward direction.	Low quality magnifier. Can be used in circuit animals and junkbots.
DC motors 	Typically 3 volts and ~1,800 rpm. Largest motor is used to transport and wind film and is attached to a gear train in the camera body. Most cameras contain 2 to 3 motors in total.	Run motors by touching battery leads to motor contacts. Can be used to create small moving junkbots from household items or as a motor-generator.

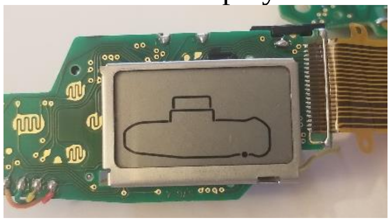
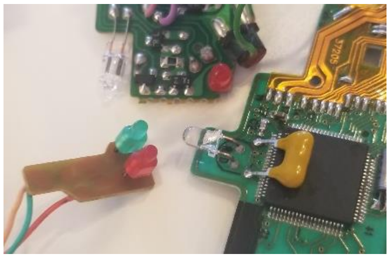
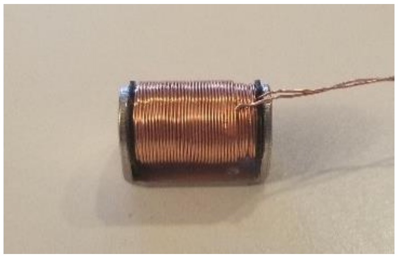
Part	Description	Project Activity
Gear motors & speed reducers 	Some cameras have speed reducers that can be extracted in one piece.	Excellent item for disassembly and reassembly due to the relatively simple design. Keep loose parts separated and contained using a paper plate.
LCD display 	Fixed to the circuit board at the top of the camera and used for external display and control of the device.	Different segments of the LCD can be lit by sweeping battery leads across electrical contacts on the circuit board.
LEDs 	Used for various external indicator lights.	The bulbs can be lit by connecting the battery leads to the correct wires or contact points on the circuit board.
Solenoid 	Attached to shutter mechanism or iris. An electric current runs through the wrapped wires which produces a magnetic field that triggers the shutter.	Can demonstrate the operation of an electromagnet by attaching the battery leads to the wires ends on the solenoid.
Miscellaneous parts 	A variety of different scrap parents, non-mechanical and non-electrical, are accumulated during the disassembly of the camera and its components.	Though there is little functionality that can be learned from these parts, they can be useful for simpler projects in constructing circuit animals or in decorating the vibrating junkbots.

Table 2: List of camera subsystems, descriptions, and project activity ideas.

3. Re-purposing project ideas

Once the disassembly phase is complete, the students can use what they learned about the functions of each part to build something new. Coming up with creative reassembly projects with the parts available has proven to be the most challenging part of the project. With the help of

OSUM volunteers, we hosted a focus group where we ran through a test run of the disassembly and brainstormed about different ways we could use the scrap parts.

The simplest re-purposing project idea is using the scrap parts for either art or building small circuit animals by gluing pieces together. This is most suited to a younger age group and was executed well with students as young as 2nd graders. The circuit animals can be taken to the next level of complexity by adding a motor and battery pack to nearly any light household item to create a vibrating creature we're calling a junkbot. Examples of the circuit animal and a junkbot can be seen in the picture included in Figure 1.

Figure 1: Two circuit animals (left and right) and vibrating junkbot (center).

In addition to making vibrating junkbots with the motors, they can also be used to create motor-generators. More suited to middle school-age students, this would teach them about different forms of power and ways to convert power. A simple motor-generator using a battery pack and two motors can be used to power an LED, as shown in Figure 2.

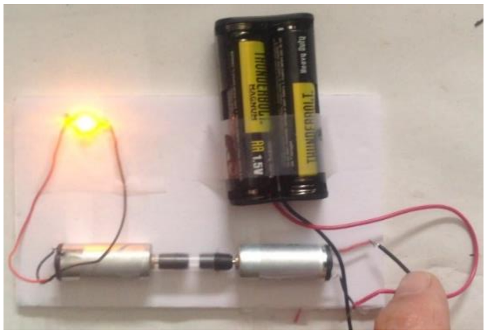


Figure 2: Simple motor-generator used to power an LED.

The internal lenses found in a camera's telescoping zoom mechanism are usually relatively high quality and function well to simply teach the students about lenses. Other than examining the lenses by eye, they can also be used to create a simple microscope by fixing it to a small camera or cellphone using rubber bands. This can be seen in Figure 3 as well as an example of a photo taken of a circuit board inside the camera using a cellphone microscope. The students enjoyed being able to more closely examine the components and were fascinated by the intricate details of the circuits. This also helps them to gain perspective on the diversity of materials inside a device and get a closer look at everything from plastics to wires to trace amounts of gold.

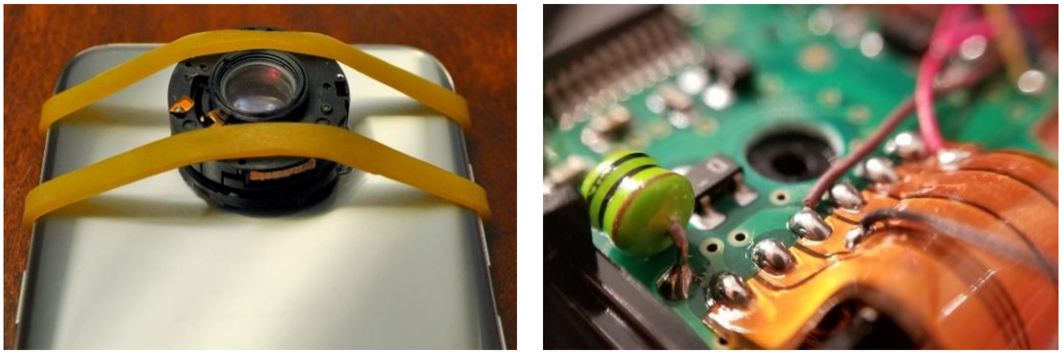


Figure 3: Cellphone microscope made from internal camera lens (left) and example of an image taken of circuit board inside camera (right).

Another project that utilizes the camera lenses is building a camera obscura. This can be done simply with a single lens and cardboard box. Cut the box in half and compress or resize one piece so that it can fit inside the other. This essentially creates a telescoping mechanism for an adjustable length box. Cut a hole in one end of the box and attach a camera lens, and another on a perpendicular side for viewing. Adding a piece of white paper inside the box opposite the lens assists in image visibility. Students learn to bring the image into focus by adjusting the length of the box to match the focal length of the lens. A picture of the camera obscura and an example of a focused image are included in Figure 4.

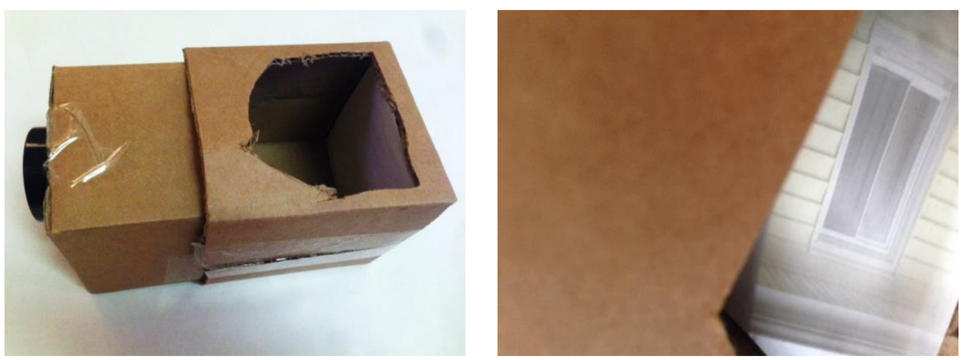


Figure 4: Camera obscura made using a disassembled camera lens (left) and an example of an image it can create (right).

Finally, we have explored the possibility of building a static electricity detector using the flash unit of the camera. Once camera's outer housing has been removed, the flash unit is easily accessed. The flash tube assembly is detached simply by cutting the wires which connect it to the circuit board, leaving some length of wire attached to both ends of the flash tube. The wires are stripped of their insulation to expose the conductors. If one of the wires was broken off during disassembly, aluminum foil can be fixed to the side of the assembly to act as the conductor. Holding one end of the flash tube assembly by the foil or wire, generate static electricity by walking on carpet, rubbing a wool sweater or balloon. Now to release the charge that has built up, complete the circuit by touching the other wire connected to the flash tube to another object. The tube will briefly light up and although the flash is weak, it can be observed in a darkened room. The more charge you build up the brighter the flash will be. An image of the "static electricity detector" can be seen in Figure 5 below.

Figure 5: Static electricity detector using a flash tube.

4. Safety considerations

The biggest safety concern in disassembling the cameras is the capacitor that is used to power the flash. Since the working condition of each individual recycled camera is unknown, attempting to fire the flash unit may not completely discharge the capacitor, so other precautions must be taken. The batteries are always removed from the cameras and they are left to sit for at least a week prior to disassembly to allow the capacitors to discharge. During the disassembly phase of the project, as soon as the camera's housing is removed, we double check that the capacitor is discharged by short-circuiting it using a screwdriver held by its insulating handle.

The other matters of safety are relatively minor in comparison to the flash capacitor. Providing safety glasses for each student is recommended since tiny pieces could be broken off if the camera is not disassembled delicately. If students are allowed to take home their scrap parts for continued tinkering, it is a small concern that a younger sibling may swallow the tiny pieces that were accumulated during disassembly. It may be best to discard any small nonfunctioning items prior to the project close. Additionally, when younger students are engaged in examining the camera's subsystems, it is best to operate the battery pack for them first to illustrate the functionality of components. Once they see proper way to power the part, they can test it once or twice on their own.

5. Recommendation for implementation

We began with the disassembly of cameras which appear to be a good for optical parts, but also contain many very small components. VCRs could be a good alternative as they have larger mechanical components and are also relatively safe and easy to disassemble.

It has also been helpful to prepare worksheets in advance that assist in helping the students think through camera functionality and give structure to the exercise. Breakpoints during the disassembly for examining and reverse engineering subsystems can be executed in this way. Talking points for explaining the scientific theories at different levels of understanding are effective in attaining active learning during the project. The educational level of the project can be even taken a step further by developing visual for the technical concepts.

As much as possible, we want stress continued learning throughout and after the project. We keep the student's parts separated with a Ziploc bag or Tupperware containers and labeled with their names from week to week. At the end of the project, they can take home their scrap parts and are encouraged to continue tinkering.

6. Conclusion

We believe that enabling playful exploration and tinkering with technology at an early age sparks curiosity, builds process skills, and personal confidence; all of which are likely indicators of a positive response to STEM topics. The three aspects of the project work together to accomplish this common goal. The disassembly serves to spark curiosity about the inner workings of the product, learn about different electrical and mechanical systems, and allows the student to gain confidence in working with technical parts. Examining the subsystems functions to teach the students about scientific principles and can also be used as an exercise in reverse engineering. Re-purposing the parts removes the need for buying many other components and has nearly infinite possibilities for projects that can be done during the time with the volunteers or at home using the scrap parts and what they have learned about their functions.

Two main advantages of the project are its low cost and only a minimal understanding of technology is required for implementation. In addition, the project can be easily scaled in time or complexity to suit nearly any situation. The time to disassembly an item is fixed, but the explanation and reverse engineering of different subsystems can be tailored for any time frame or age group. The re-purposing projects also allow for a great deal of variability in complexity based on the perceived expertise of the students. There does not appear to be a difference between boys and girls, for the age group we have seen, in their ability to engage with the project. We believe that disassembling and component reuse from recycled consumer electronics may be a practical and useful activity for introducing science, technology, and engineering, and thus is deserving of further investigation. We are open to ideas about items to disassemble and repurpose, as well as any general comments on the project. A discussion forum at the bottom of the project webpage can be used to submit feedback (opticsumich.com/outreach/projects/disassembly).

7. Acknowledgements

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