

Using Product Archeology to Increase High School Student Interest in Engineering Technology Majors

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Abstract

This paper reports the results of a novel Engineering Technology (ET) education recruiting activity where teams of high school students dissected consumer products and matched the discrete parts and assemblies to engineering functions printed on a card. The theory of the event is to introduce students to engineering design via product archeology; the combination of product dissection with functional analysis. Product dissection is the disassembly of products in order to understand technical aspects of their design, e.g. "how are products constructed?". Functional analysis is the study of the intended behavior of a component in a system, e.g. "what was the purpose of that part?". The goal of the activity is that students could connect the "what" and the "how" of engineering design in a compact and engaging event to positively influence their perceptions of ET as a college major. The impact of the recruitment event was assessed via surveys of students' perceptions using Likert style and open response questions. Results indicate that the event was viewed overwhelmingly positively in the areas of engagement and understanding, but less successful in recruitment effect to the specific college.

1. Introduction

Purdue University New Albany (PUNA) is part of Purdue Polytechnic statewide system, serving students the Southern Indiana/Greater Louisville KY metropolitan region. PUNA is a small commuter school, offering Bachelor of Science degrees in Engineering Technology (ET) disciplines and producing graduates that frequently stay in the region when joining the workforce. Like many small schools and commuter programs, PUNA relies heavily on local recruiting activities with area high schools to meet enrollment goals. A major recruitment strategy has been for ET faculty to develop and host hands-on workshops for high-school students. Typically, these events focus on the applied nature of ET by using a learn-by-doing approach.

Prior faculty-developed recruiting events at PUNA were successful in developing positive perceptions of ET in potential students. However, they required significant time commitments from both faculty and the student attendees which limited the number of events that could be offered. A strategy was developed to increase the effectiveness of the recruiting events, consisting of three tiers (Figure 1) arranged in a funnel. The first tier is *Awareness* of PUNA and ET majors, followed by *Interest* in ET majors/careers, and finally *Recruitment* of interested students into PUNA ET majors.

Tier 1 consists of a Boiler Visit, which is a "chalk-and-talk" style presentation that explains ET and PUNA to student groups. While not hands-on, Boiler Visits focus on introducing students to ET and differentiating the program from engineering by emphasizing the project and laboratory-based curriculum. They require one or two faculty to deliver, need less than 15 minutes of advanced preparation, and are less than one hour in length. Additionally, these programs can be delivered to large groups of students and have little to no operational costs. On the other end of the spectrum, Tier 3 is Purdue Mission to Mars (PM2M) (Turner et al. 2016), a design-project event where students build, program, and test robots. PM2M typically involves five or more faculty, more than a full day of preparation, and is seven hours in length (or more). It can be delivered to a group of up to 50 and has high operation costs due to the need for robot kits and consumables.

The subject of this paper is the development, initial implementation, and assessment of the Tier 2 event, BoilerUp! Bingo. Serving as a "2nd-touch" opportunity with potential applicants, the event was designed with the following criteria:

- Focus on engineering technology design via a hands-on lab style activity.
- Related to both electrical and mechanical engineering technology.
- Sub 1 hour and 45 minutes operational time to align with student and faculty schedules.

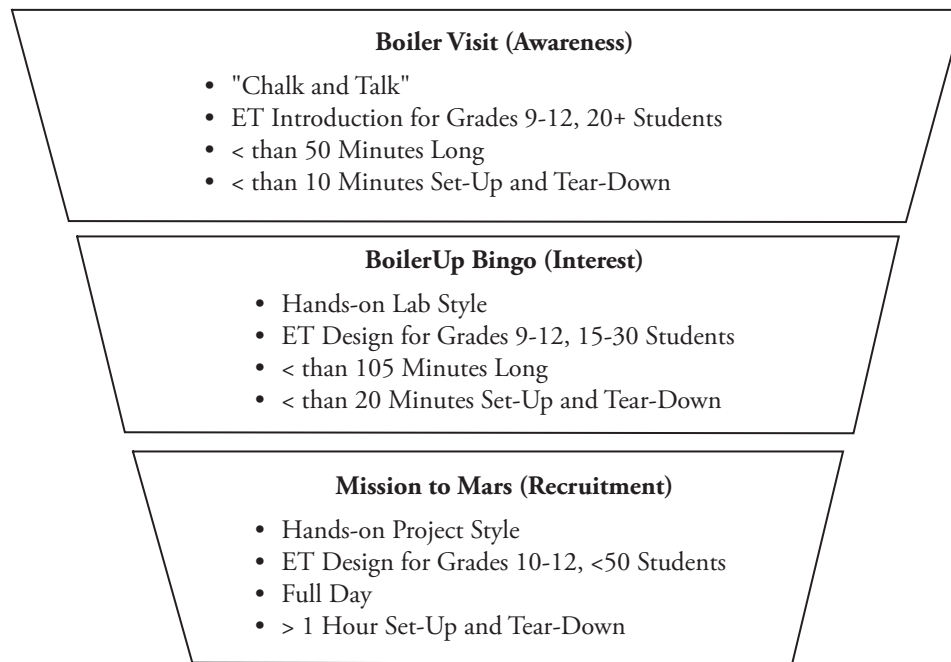


Figure 1. Recruiting event "funnel" strategy.

- Scalable to a typical high school class size of less than 50 students.
- Easily repeatable for multiple student groups:
 - o Less than 20 minutes of setup.
 - o Less than 20 minutes of clean up.
 - o Less than 1 hour of advanced prep required to train new faculty facilitators.
- Cost effective at less than \$5 dollars per student in materials.
- Effective at generating interest in ET programs:
 - o Perceived as fun and interesting.
 - o Perceived as improving understanding of engineering technology.
 - o Improved interest in attending specific college programs.

Section 2 of the paper describes the theoretical design frameworks of Product Dissection and Functional Analysis and how they were operationalized as a recruiting event. Section 3 provides an event description. Section 4 presents the quantitative and qualitative results of the event data. Conclusions and future work are outlined in Section 5.

2. Theoretical Frameworks of Engineering Design

BoilerUp! Bingo was conceived as a fun way to introduce students to engineering design thinking.

Many common design education activities are approached from a problem-solving perspective, i.e. students are asked to solve problems. Examples include egg-drop challenges or building bridges from pasta noodles. In contrast, BoilerUp! Bingo is based in the frameworks of Product Dissection and Functional Analysis which have their roots in product and mechanical design.

2.1 Product Dissection

Product Dissection is the deconstruction or disassembling of consumer products to infer design thinking from artifacts. It is a technique used in engineering design courses to answer the question "How did past engineers solve a problem?". It is premised on the idea that a hands-on deconstruction of a consumer product can help students develop a vocabulary of engineering, understand mechanical artifacts, and be aware of the engineering design processes (Sheppard 1992). The roots of product dissection in engineering education are from Stanford University, where mechanical engineering students dissected products including bicycles. These activities were followed by relevant lectures, such as discussions on loads on brake systems, (free-body diagrams), material selection for calipers, and material characterization/tests (Sheppard 1992). One of the primary motivations for the development of dissection-based courses is to bridge the gap between theoretical textbook learning and the hands-on practical experience often required to understand how products are designed, how they function and how they are made (Eggert 1996), (La-

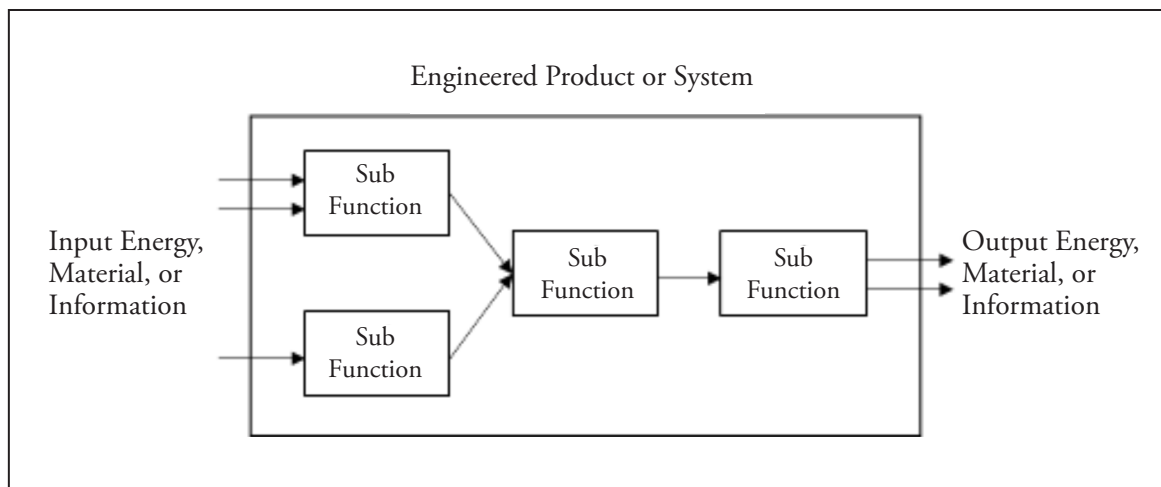


Figure 2. Example functional decomposition subfunction structure.

mancusa, Jorgensen, and Fridley 1996). Extensions of this technique have included investigations into how product design is influenced by global, environmental, and economic considerations (Lewis et al. 2011), (Lewis et al. 2013).

2.2 Functional Analysis

Originally developed to improve the creation of new engineered systems (Beitz, Pahl, and Grote 1996), functional analysis is frequently used in the engineering design process to describe an engineering product in terms of abstracted functions that are independent of specific technologies (Otto and Wood 2001), (Ulrich, Eppinger, and Yang 2008). Often this is described as setting “what a system must achieve or do” as opposed to engineering form, or “how a system will achieve or do”. Typically, this is performed by considering a system as a “black box” that converts a specific set of inputs (“flows” of energy, material, information) into outputs using one or more subfunctions (Figure 2). For example, a blow dryer is an engineered system that receives inputs of air (material), electricity (energy) and on/off (information) and converts them to an output of heated air. This is achieved via a variety of sub functions and flows, such as converting electrical energy to heat or motion. Identification of the abstracted sub-functions required by an engineered system to perform its primary function is a design step often called “functional decomposition”.

Design abstraction in the form of functional analysis is often taught in engineering design courses (Booth, Reid, and Ramani 2013) and has been previously used as a framework to explain engineering and technology to both introductory engineering students and non-majors through ap-

plication to products such as a hair dryer, vacuum cleaner, and coffee maker (Krupczak 2010).

2.3 BoilerUp Bingo to Explain Engineering Design

Based on their prior use in engineering education, the previously described techniques of product dissection and functional analysis were operationalized into the BoilerUp Bingo event. The goal is to expose participants in the event to engineering design thinking and methods, specifically how engineers solve previous problems and how physical components are used to achieve abstracted functions, i.e. learn what it means to think like an engineer to solve problems and to understand how designed products and systems work.

For product dissection, three consumer products were chosen; a video game controller, blow dryer, and radio controlled (RC) car with remote (Figure 3). Factors considered in product selection included the likelihood of familiarity by high-school students, general appeal to high-school students, inclusion of both electrical and mechanical systems, ease of dissection using common tools, sufficient complexity as to contain interesting functions, and not overly complex as to be too difficult to analyze by novices.

For functional analysis, decomposition techniques were adapted from (Little, Wood, and McAdams 1997) and (Stone and Wood 1999) in which the requirements of engineered systems are described as in Figure 2 using functions (a description of an item's task in verb-object form) and flows (changes in material, energy, or information between an item's sub-functions). Prior work has identified that approximately twenty functions can be used to accurately and completely describe all major operations of engineered systems (Little, Wood, and McAdams 1997), which are commonly used via verb-noun pairings



Figure 3. Original and dissected consumer products for BoilerUp Bingo. From the left, a game controller, a hair dryer and a remote-controlled car.

with the flows they operate on (e.g. separate material, transmit force). To organize the functions, a bingo card (Figure 4) was developed with the squares containing the adapted engineering functions. A definition and example(s) were included for each function.

	A	B	C	D	E
1	Stop	Measure	Absorb	Slide	Indicate
2	Stick	Separate	Align	Translate	Seal
3	Switch	Convert		Supply	Couple
4	Store	Push	Stabilize	Distribute	Cover
5	Sense	Transmit	Rotate	Brace	Secure

A. Stop

- i. To cease, or prevent something from occurring.
- ii. Example: A reflective coating on a window *stops* the transmission of UV radiation through a window. A switch *stops* electricity from flowing in an electric circuit.

Figure 4. Bingo card with simplified engineering functions and example definition for "Stop" function.

The functions used on the card were adapted from those developed by Little and Stone such that they could be utilized by novice designers (i.e. high school students). There are cases in the referenced work where proposed functions have similar definitions, for example indicate vs. display. Although originally defined in (Stone and Wood 1999) as two different functions, they were not considered unique enough concepts to be clearly distinguished by students. For example, does a red LED indicate (to make something known to the user) that power is on or display (to show a visual effect)? This confusion was further complicated by the examples from (Stone and Wood 1999) which were "A small window in the water container of a coffee maker indicates the level of water in the machine." and "The face and needle of an air pressure gage display the status of the pressure vessel." for indicate and display, respectively. Additionally, multiple new functions were added to simplify the exercise. For example, one function of a tire is to provide traction between a tire and a surface, and a rubber coating on a button provides a similar function between the finger and button. Although these could be viewed as applications of the function secure (to firmly fix a material or energy path), this level of connection was considered too difficult. Instead, a related function of "stick: to cause a resistance to a change in motion or direction" was created. A second example is the function of a protective case, which can be seen as a support function (to firmly fix a material into a defined location). This was changed to "cover: to put something in place in order to protect or conceal something".

reward and are then challenged to score a cover-all bingo card (all function squares on the card are covered with a correct component/device/sub-system). Early runs of the event indicate that 40 minutes is sufficient time for all teams to score a bingo, and for most teams to score a cover-all.

3.3 Explanation

The third stage of the event returns to large group guided discussion where the teams are asked how the components identified contribute to the overall function of the product. This challenges the students to think about how the individual components of each product work together to achieve a major function, the reverse of the process that was used to analyze the #2 pencil. This discussion is guided so that the following functional definitions of the products are identified:

- Game Controller: to communicate with a game system by collecting input from a human's hands and to provide user feedback via light, vibration, and tactile response.
- Blow Dryer: to provide a flow of hot hair to increase the evaporation of water from a surface or material and to assist in hair styling.
- RC Car: to control the speed and direction of a model vehicle from a distance by collecting and transmitting inputs from a human's hands.

3.4 Real World Connection

In the fourth and final stage of the event, faculty facilitators discuss the role of engineering technology in product design and manufacture via presenting on their own real-world engineering design experiences.

4. Results and Discussions

4.1 Demographics and Selection

The BoilerUp Bingo event has been offered twice to a total of 42 high school students. Students were part of Indiana Gear Up (Johnson et al. 2023), a program that helps prepare Indiana students from lower income communities to start college successfully. Students at high schools participating in Indiana Gear Up voluntarily signed up for the event. 24 of the program participants identified as female, and 16 as underrepresented minorities. On day one, 32 students were separated into eight groups, and on day two, ten students were separated into four groups.

4.2 BoilerUp Bingo Results

In order to build self-perception of STEM efficacy, the bingo activity was designed such that a single-line bingo could be achieved with any of the given products. Of the 12 groups in this sample, all were able to complete a single-line bingo. The fastest team reached the goal in 15 minutes using the RC car, and the longest achieved 'bingo' in 45 minutes using the hair dryer. The approximate mean time to completion of a single-line bingo across all groups was 25 minutes. It was observed that the time to completion depended upon the faculty facilitator evaluating the component and function pairings, with some facilitators interpreting the engineering functions more narrowly than others, resulting in longer completion times. All teams that finished before the allotted time were given the chance at a cover-all bingo. On the first day, teams were allowed to disassemble an additional product to achieve this. Of the eight groups, four achieved a cover all. On the 2nd day, teams were restricted to one product for the entire activity. All four groups were able to achieve a coverall. Figure 7 illustrates the high level of student interaction during the event.



Figure 7. Student participation in BoilerUp bingo.

4.3 Survey Results

Student perception was evaluated using a post-event survey. Questions one through five had students rate their agreement with a provided statement on a scale from 1. *Do Not Agree at All* to 4. *Agree a Lot*. Descriptive statistics for the student responses are given in Table 1. The overall high scores for Q1 to Q4 indicate that the overall student perception of the event was as intended: a fun activity that engaged their thinking in a way that improved their self-perceived understanding of engineering technology and engineering product design. The lower score of 2.6 for Q5 should be viewed in the context that Purdue New Albany only offers engineering technology degrees, which many students will not be intrinsically interested in.

Questions six and seven of the survey were open-ended response questions asking the students to provide comments on what aspects of the event appealed to them the most and what they would like to see improved. Table 2 summarizes the overall themes found in the responses (multiple themes can be contained in a single student's response). Results show that the majority of students enjoyed the hands-on nature of the event and had no suggestions for changes.

4.4 Facilitator Observations

At the end of each day the faculty facilitators were asked to provide a one paragraph observation of the event. Overall, faculty facilitators shared two major observations. First, they believed that the students were engaged with the activity and enjoyed taking things apart. This agrees with the student reported survey data and supports the overall conclusion that the event was successful in appealing to student interests. The second observation is related to the students' understanding of engineering design and functional analysis. Generally, the faculty reported that students required some assistance with identification of engineering function and overall understanding of engineering design thinking. The following responses illustrate these points:

"All of the student groups were engaged with the activity. They started taking apart the game controller without any hesitancy, including

Table 1. Post event survey data. Sample Size = 42.

Statement	Mean	SD
Q1. The activity was fun.	3.88	0.25
Q2. The activity made me think.	3.69	0.45
Q3. The activity improved my understanding of engineering technology.	3.55	0.49
Q4. The activity improved my understanding of how products are designed.	3.55	0.61
Q5. The activity increased my interest in attending college at Purdue New Albany.	2.60	0.89

Table 2. Summary of themes found in open response questions.

Theme	Number of Comments Containing Theme
<i>Something I really liked about today's activity was:</i>	
Hands On	27
Real World Application	6
Fun Game	6
Increased Knowledge	8
Instructor Interaction	5
Teamwork	1
<i>Something that I think could be improved about today's activity was:</i>	
No Suggestions	21
Not Enough Interaction with College Students	2
Disassembly Too Easy	2
Not Enough Variety in Product Selection	2
Disassembly Too Small	1
Engineering Functions Unclear	1
Event Too Long	1
Event Too Short	1

breaking pieces apart. They were mostly successful with function identification given the reading and their background knowledge, but they did require assistance on a few terms... Most of the mechanical elements were more familiar to them, but there were multiple teams asking about electrical components they had heard of (LED and capacitor) and what they looked like on the board."

"Students seemed to gain some understanding of the engineering design mindset from the activity. Since every team in my group chose the game controller, we were able to have a class-wide discussion of the hair dryer and RC car functions without anyone having seen the

inside of them. ... Students were asked about the function of the hair dryer, which they initially replied “to dry hair”. Once prompted with “how?”, the group was able to deconstruct “blow hot air” into a smaller and smaller set sub-functions that contribute to the overall function. Similarly, they seemed to have a realization that the RC car contained many of the same components and engineering functions as the game controller and blow dryer, but that the placement interaction of the elements is what determined the overall operation.”

5. Conclusions and Future Work

BoilerUp Bingo is a sub 2-hour engineering technology outreach program designed to be entertaining, low-cost, and easily repeatable with little setup or tear-down time. Program participants learned about engineering design thinking by tearing apart a consumer product (product dissection) and identifying engineering functions for the dissected components (functional analysis). Initial offerings of the activity were promising, with students reporting that the event was entertaining and improved their understanding of both ET and product design. These results are highly encouraging given the large percentage of female and URM participants in the pilot. However, no data has been collected to evaluate efficacy of the program in recruiting students into ET majors. In the future, the authors plan to collect longitudinal data of incoming freshman to better understand the impact of the recruiting strategy outlined in Figure 1.

In addition to recruiting, BoilerUp Bingo could be utilized as part of an engineering design course or course sequence such as “design thinking” or “design spine”. Functional analysis is widely viewed as a difficult concept, especially when employed as a design activity in capstones and similar courses. BoilerUp Bingo introduces the concept in a way that is engaging and understandable to students at an earlier stage of their education and may provide a foundation for deeper and more critical discussion in advanced courses.

References

Beitz, W, G Pahl, and K Grote. 2013. *Engineering Design: a Systematic Approach*, 3rd ed. Springer Science & Business Media.

Booth, Joran W, Tahira Reid, and Karthik Ramani. 2013. "Understanding Abstraction in Design: A Comparison of Three Functional Analysis Methods for Product Dissection." In *Proceedings of the International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*.

Eggert, Anthony. 1996. "Mechanical Dissection; Bridging the Gap Between the Theoretical and Physical World." In *Proceedings of the Technology-Based Re-Engineering Engineering Education Proceedings of Frontiers in Education FIE'96 26th Annual Conference*.

Johnson, Carla C, Toni A May, Janet B Walton, and Virginia Bolshakova. 2023. "Supporting Urban School Students' Preparedness for Post-Secondary Study Through Gaining Early Awareness and Readiness for Undergraduate Programs (GEAR UP)." *Journal of Higher Education Theory & Practice* 23 (11).

Krupczak, John. 2010. "Using Functional Analysis as a Framework for Understanding Technology." In *Proceedings of the 2010 ASEE Annual Conference & Exposition*.

Lamancusa, John S, Jens E Jorgensen, and James L Fridley. 1996. "Product Dissection-A Tool for Benchmarking in the Process of Teaching Design." In *Proceedings of the Technology-Based Re-Engineering Engineering Education Proceedings of Frontiers in Education FIE'96 26th Annual Conference*.

Lewis, Kemper, Deborah A Moore-Russo, Omar M Ashour, Timothy W Simpson, Gül E Okudan Kremer, Xaver Neumeyer, Ann F McKenna, and Wei Chen. 2011. "Teaching the Global, Economic, Environmental, and Societal Foundations of Engineering Design Through Product Archaeology." In *Proceedings of the 2011 ASEE Annual Conference & Exposition*.

Lewis, Kemper, Deborah A Moore-Russo, Gül E Okudan Kremer, Conrad Tucker, Timothy W Simpson, Sarah E Zappe, Ann F McKenna, Adam R Carberry, Wei Chen, and David W Gatchell. 2013. "The Development of Product Archaeology as a Platform for Contextualizing Engineering Design." In *Proceedings of the 2013 ASEE Annual Conference & Exposition*.

Little, Aaron D, Kristin L Wood, and Daniel A McAdams. 1997. "Functional Analysis: A Fundamental Empirical Study for Reverse Engineering, Benchmarking and Redesign." In *Proceedings of the International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*.

Otto, Kevin, and Kristin Wood. 2001. "Product Design: Techniques in Reverse Engineering and New Product Development: Techniques in Reverse Engineering and New Product Development." Upper Saddle River, NJ: Prentice Hall.

Sheppard, Sheri D. 1992. "Mechanical dissection: An Experience in How Things Work." In *Pro-*

ceedings of the Engineering Education: Curriculum Innovation & Integration:6-10.

Stone, Robert B, and Kristin L Wood. 1999. "Development of a Functional Basis for Design." In *Proceedings of the International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*.

Turner, Matthew, Joe Dues, Tim Cooley, Rustin Webster, Richard Kopp, Andrew McCart, and Dani Reynolds. 2016. "Purdue mission to mars: Recruiting High School Students into a Polytechnic College." *Journal of Engineering Technology* 33 (2):8.

Ulrich, Karl T, Steven D Eppinger, and Maria C Yang. 2008. *Product Design and Development*. Vol. 4. Boston: McGraw-Hill Higher Education.

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