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Using Product Dissection to Integrate Product Family Design Research into the Classroom and Improve Students' Understanding of Platform Commonality*

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In this paper we describe a product dissection activity that has been developed for a graduate course on product family design to improve students' understanding of platform commonality. This past spring, the product dissection activity served a second purpose, namely, it provided an opportunity to engage students in product family design research in the classroom by having them participate in a study to evaluate the variability in the Product Line Commonality Index (PCI), a commonality index from the literature. The product dissection activity consisted of five teams dissecting and analyzing three different families of products, each containing four products. Based on their results, we identified three main sources of the variability that occur during the dissection of the products and calculation of the PCI: different levels of dissection, parts omitted from the analysis, and different values for the factors used to compute the PCI. Recommendations for reducing the variability are given based on our findings. Finally, an assessment of the students' learning reveals that the activity significantly improved their understanding of platform commonality.

Keywords: Product dissection; commonality; hands-on learning; product family design

INTRODUCTION

PRODUCT DISSECTION has been used in a variety of ways to actively engage engineering students in their learning. Few would argue that engineers are more likely to be active rather than reflective learners [1], and the benefits of using 'hands-on' activities such as product dissection are many. For instance, product dissection has been successfully used to help students identify relationships between engineering fundamentals (e.g., torque and power) and hardware design (e.g., a drill) [2]. It has also been used to help teach competitive assessment and benchmarking [3, 4]. Product dissection is part of the freshmen Product and Process Engineering Laboratory at North Carolina State University where users take turns playing the role of user, assembler, and engineer [5]. Sheppard [6] was among the first to develop a formal course in product dissection at Stanford University [31], and a similar course in product dissection [32] was developed as part of the Manufacturing Engineering Education Partnership between Penn State, University of Washington, and University of Puerto Rico-Mayaguez [7]. Finally, product dissection has also been used, with varying degrees of success, in conjunction with multimedia case studies at Berkeley [8], Stanford [9], and Penn State [10].

The focus in this paper is on the product dissection activities that have been used each spring for the past five years as part of a graduate course on product family design [33] that is cross-listed in both mechanical engineering and industrial engineering at Penn State. These dissection activities are unique in that rather than dissect a *single* drill or coffee maker as is done in the aforementioned courses, students in this course work in multidisciplinary teams to dissect *multiple* products from a single family. Examples from past dissection activities include one-time-use cameras (Kodak and Fujifilm), coffeemakers (Braun, General Electric, Mr. Coffee), Versapak® and Firestorm® toolsets (Black & Decker), corded drills and screwdrivers (Craftsman, DeWalt, and Skil), and portable audio-stereo devices (Sony, Aiwa, and Panasonic). However, any set of 3-4 relatively inexpensive appliances (e.g., shop vacuums, mixers, hand blenders, toasters, ice tea brewers, irons, hair dryers, electric toothbrushes) will suffice. The multidisciplinary nature of the team creates a synergistic effect between the mechanical engineers and industrial engineers: the mechanical engineers are usually better at determining why parts are designed the way they are (e.g., why a roller bearing is used versus a ball bearing) while the industrial engineers are more adept at determining how parts are manufactured

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(e.g., cast versus forged). So, the teaming allows them to not only learn about the products they are dissecting but also learn from each other.

Through dissection, students are able to identify firsthand how different companies have resolved the inherent tradeoff between commonality and distinctiveness within a product family: when designing a product family, designers must carefully balance the commonality of the platform and the distinctiveness of the individual products within the family [11]. There are many examples that can be used to illustrate when platform commonality has created a competitive advantage for a company, likewise when it has backfired. Volkswagen, for instance, has experienced both recently. At Volkswagen, the common elements in the platform are the floor group, drive system, running gear, along with the unseen part of the cockpit as shown in Fig. 1. This platform is shared across several models as well as all of its brands (i.e., Volkswagen, Audi, Seat, and Skoda). Volkswagen reportedly saved $1.5 billion per year by using a common platform across its four brands and was very successful in producing new models [12, 13], but as word spread about their platform strategy, customers started buying lower-end models instead of the higher-end ones, which decreased their profitability [14]. Volkswagen has since announced plans to overhaul their image, particularly their high-end Audi brand, to distinguish the individual brands more from each other [15, 16]. Other examples can be found in the recent review of product platform design strategies in [17].

While examples like that of Volkswagen are useful in conveying the merits (and potential drawbacks) of platform commonality, few students have a true appreciation for the extent to which different companies utilize platform commonality within their products. They are often flabbergasted when they learn that 80–90% of the non-differentiating components in a Sony Walkman® are common [19] and that 250+ models have been created from only three basic Walkman® platforms [20]. Given that people generally remember 10% of what they read, 20% of what they hear, 30% of what they see, 50% of what they hear and see, 70% of what they say, and 90% of what they say and do [21, 22], there is much to be gained in pairing product dissection with lectures and examples of platform commonality. The pedagogical methodology used to teach students about platform commonality using product dissection is described in the next section. This follows with an overview of the experimental methodology recently developed for the dissection itself. Results from the experiment are presented and discussed, which is followed by an assessment of the students' learning from the activity. Closing remarks and future work conclude the paper.

PEDAGOGICAL METHODOLOGY

Stice [22] found that students' retention of knowledge increases to 90% when students are engaged in all four stages of Kolb's learning cycle compared to only 20% when only the first stage, Abstract Conceptualization (e.g., lecturing) is involved. Kresta [23] notes that it is important for students to see important topics in a course at least three times and that reinforcing hands-on demonstrations with lectures and assignments improves the learning environment for students. Consequently, the pedagogical methodology employed to teach students about platform commonality combines (1) lectures, (2) discussion, and (3) dissection to sequentially traverse the first three stages of Kolb's learning cycle, namely, Reflective Observation ('watching'), Abstract Conceptualization ('thinking'), and Active Experimentation ('doing') [1]. The dissection also emphasizes Concrete Experience ('feeling'), which is reinforced later in the semester when students are asked to consider the implications ('What ifs') of commonality on the manufacturing and production processes given what they learned and experienced earlier. A brief overview of the lectures, discussion, and dissection follow.

The *lectures* typically consist of two class periods

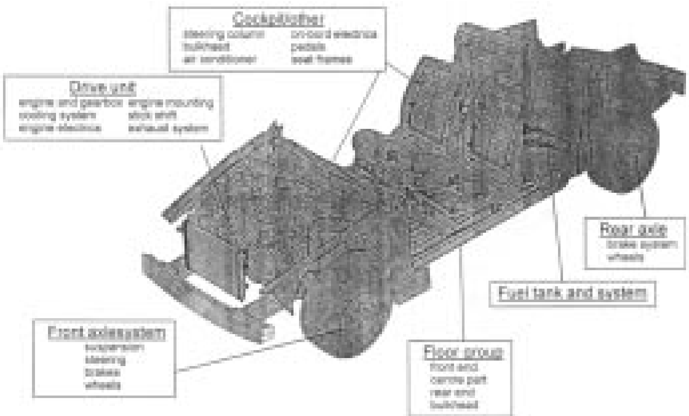


Fig. 1. Volkswagen's platform definition [18].

wherein PowerPoint slides [34] are used to cover the advantages and disadvantages of commonality, overview several commonality indices that are available in the literature, and then go into detail about the Product Line Commonality Index (PCI) [19], which is computed later in the dissection as discussed in the next section.

The *discussion* that follows the lectures uses a jigsaw method [24, 25] to divide the class into 4–6 groups first by discipline (e.g., R&D, marketing, engineering, manufacturing, service, customers) and then by industry (e.g., automotive, aircraft, computer, furniture, telecommunications, power tools). Each grouping is given 10 minutes to discuss when and why commonality is (i) good and (ii) bad from their perspective. For example, students in the aircraft group might recall from the earlier lecture that Airbus has enjoyed a competitive advantage over Boeing due to improved commonality among their aircraft, particularly in the cockpit [26] while those in automotive group might remember that too much commonality damaged Chrysler's reputation in the 1980s due to over-usage of the K-car platform: engineers were accused of having 'fallen asleep at the typewriter with our finger stuck on the K key' [27]. It is during this second stage that the cooperative nature of the jigsaw method comes into play: each new group (e.g., computer manufacturer) has at least one person from the old group (e.g., manufacturing) so that all disciplines are represented and discussed. This encourages students from the first group to share what they learned from the first discussion and makes them accountable for contributing to the new discussion topic. At the end of the 10 minutes, each new group is asked to summarize their discussion to the class.

The product *dissection* activity then follows the lectures and discussion. It requires 2-3 hrs to complete, which has been successfully accomplished in two 75-minute class periods. This past spring, we were able to schedule a 3-hr laboratory one evening instead in the Design Studio and Product Dissection Laboratory within the Center for Engineering Design and Entrepreneurship [35]. The laboratory has basic tools for dissection (e.g., screwdrivers, wrenches, pliers, etc.) while providing ample room for laying out the parts for analysis; the room also has several computers that were made available to each group to complete an Excel worksheet to compute a commonality index, namely the PCI. The Excel worksheet and overview of the experiment can be downloaded from online [36]. Fig. 2 shows a picture of the students working in the lab during the dissection. An overview of the experimental methodology is given in the next section.

EXPERIMENTAL METHODOLOGY

This past spring, the product dissection activity served a dual purpose. First, it was designed to improve the students' understanding of commonality within a family of products while also giving them an opportunity to analyze the commonality within a family of products using the Product Line Commonality Index (PCI) [19], which is defined as:

$$PCI = \frac{\sum_{i=1}^{P} n_i * f_{1i} * f_{2i} * f_{3i} - \sum_{i=1}^{P} \frac{1}{n_i^2}}{P * N - \sum_{i=1}^{P} \frac{1}{n_i^2}} * 100 \quad (1)$$

where:

- P = Total number of non-differentiating components that can potentially be standardized.
- N = Number of products in the product family.
- n_i = Number of products in the product family that have component i.
- f_{1i} = Size and shape factor for component i = Ratio of the greatest number of models that share component i with identical size and shape to the greatest possible number of models that could have shared component i with identical size and shape (n_i).
- f_{2i} = Materials and manufacturing processes factor for component i = Ratio of the greatest number of models that share component i with identical materials and manufacturing processes to the greatest possible number of models that could have shared component i with identical materials and manufacturing processes (n_i).

Fig. 2. Product dissection studio.

f_{3i} = Assembly and fastening schemes factor for component i = Ratio of the greatest number of models that share component i with identical assembly and fastening schemes to the greatest possible number of models that could have shared component i with identical assembly and fastening schemes (n_i).

Second, the data was used as part of a larger study that was being conducted to compare and contrast ease of use, consistency, sensitivity, and repeatability of several commonality indices in the literature [28, 29]. While some commonality indices are based only on information in a Bill of Materials, other indices, such as the PCI, are more subjective in nature with results varying from user to user. For example, when computing the PCI, the value of f_{1i}, f_{2i} and f_{3i} for each component can be vary depending upon the user's knowledge and point of view: what exactly is the 'same size' or 'same shape', what if two parts are identical except in color, etc.

In order to quantify the subjectivity in the PCI, the product dissection activity was set up such that the results from each group's analysis could be pooled to examine the *variability* within the estimates of platform commonality using the PCI. This was accomplished using five teams of four to five people, and three families of products consisting of four products each: Kodak and Fujifilm one-time-use cameras and Mr. Coffee coffeemakers (see Table 1). These families were chosen so that comparisons could be made both within a family and across similar families (i.e., the one-time-use cameras). The products were also readily available in the market and relatively inexpensive—the cameras cost \$5-\$12 each while the coffeemakers cost \$20-\$50 each.

Each team was instructed to perform the following tasks:

1. Read an overview of the experiment and sign the informed consent form [36].
2. Dissect each product in the family to the lowest level possible, i.e., to the point when the parts cannot be divided into further subassemblies.
3. Identify the different parts as being either: *common* to each product within the family, *variants* of one another in each product within the product family, or *unique* to each product within the product family.
4. Take a picture of each product after it is dissected using the digital camera provided in the laboratory. This picture should show all the components for each product and should include captions that should be used when completing the Excel spreadsheet.
5. Complete the Excel spreadsheet template [36] where the rows represent the parts sorted by name, and the columns represent the different products in the family. An additional column was used to identify the commonality among parts in each product.
6. Compute the PCI for one of the other product families that was dissected by another team using a new Excel spreadsheet template.

The ordering for dissection and PCI computation is shown in Table 2. The 'Dissect + PCI' is the first product family dissected and analyzed by this team; the 'PCI' indicates the product family dissected by a different team for which this team also computed PCI. For example, Team 1 dissected and computed the PCI for the first set of Mr. Coffee coffeemakers, and they then computed the PCI for the second set of Kodak cameras, which was dissected by Team 5. At least

Table 1. Products dissected and analyzed

Family	Product 1	Product 2	Product 3	Product 4
Kodak (2 sets)	MAX Outdoor	MAX Flash	Funsaver 35	MAX Water & Sport
Fujifilm	Quicksnap Outdoor	Quicksnap flash – old	Quicksnap flash - new	Quicksnap waterproof
Mr. Coffee (2 sets)	TFX20	TFX23	TF13	ESX33

Table 2. Team ordering for dissection and anlaysis

Team	Mr. Coffee 1	Mr. Coffee 2	Kodak 3	Fuji 4	Kodak 5
1	**Dissect + PCI**				**PCI**
2		**Dissect + PCI**		**PCI**	
3			**Dissect + PCI**	**PCI**	
4			**PCI**	**Dissect + PCI**	
5		**PCI**			**Dissect + PCI**

three PCI values are computed for each product family due to the balanced nature of the ordering. Results from the experiment are given next along with samples of completed Excel spreadsheets.

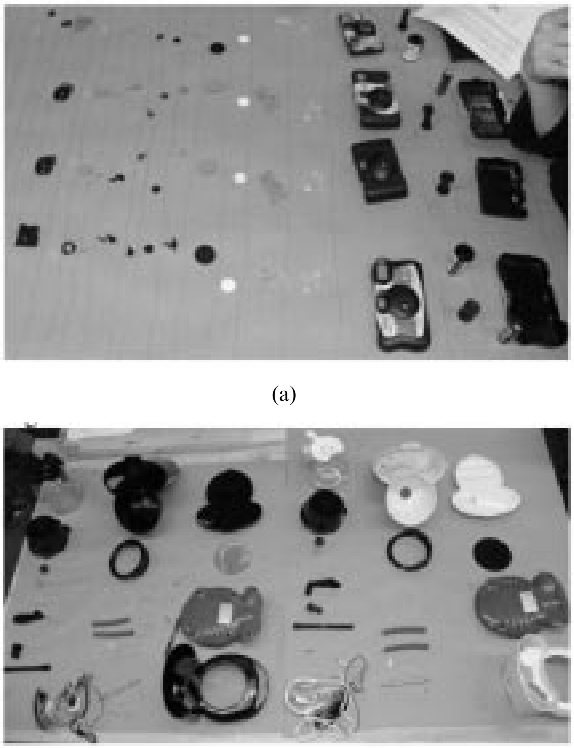
SAMPLE RESULTS AND DISCUSSION

An example of an Excel spreadsheet that was completed by a team to compute PCI is shown in Table 3. For each product, there are two columns: the first contains a number (1, 2, 3 or 4) that indicates if the part is common between different products. For example, if two products have the same number for a given part (row), then they share that component. If the number is different in each column for a given part, then all of the products use variants of the same part. The second column is a computational aid: 1 if the part is used in the corresponding product, 0 otherwise. So looking at the first two rows in Table 3, we see that each product has a different Back Cover (Row 1), but the Battery (Row 2) is the same in the FunSaver 35 and the Max Flash—it does not exist in the Waterproof or Max Outdoor models since they do not have a flash). These two columns are used to automatically compute n_i, the total number of common or variant parts of this type in the family. The team also completes the f_1, f_2 and f_3 columns for each part after they reach

Table 3. Example of completed spreadsheet for Kodak one-time-use product family

Parts	Water & Sport		Max Flash		Max Outdoor		FunSaver 35		ni	1/ni^2	Size & geometry f1	Material & Manufacturing f2	Fastening & assembly f3	ni*f1*f2*f3
Back Cover	1	1	2	1	3	1	4	1	4	0.063	0.500	1.000	0.750	1.500
Battery		0	1	1		0	1	1	2	0.250	1.000	1.000	1.000	2.000
Cam	1	1	2	1	2	1	3	1	4	0.063	0.500	0.500	1.000	1.000
Exposure Counter Wheel	1	1	2	1	3	1	4	1	4	0.063	0.250	1.000	1.000	1.000
Film	1	1	1	1	1	1	1	1	4	0.063	1.000	1.000	1.000	4.000
Film Axle	1	1	2	1	2	1	3	1	4	0.063	0.500	1.000	1.000	2.000
Flash Assembly		0	1	1		0	2	1	2	0.250	0.500	0.500	1.000	0.500
Flash Cover		0	1	1	0	1	1	1	3	0.111	1.000	1.000	1.000	3.000
Frame	1	1	2	1	3	1	4	1	4	0.063	0.500	1.000	1.000	2.000
Front Cover	1	1	2	1	3	1	4	1	4	0.063	0.500	1.000	0.750	1.500
High Energy Lever 1	1	1	2	1	3	1	4	1	4	0.063	0.750	0.500	0.750	1.125
High Energy Lever 2	1	1	2	1	2	1	3	1	4	0.063	0.750	0.500	1.000	1.500
High Energy Lever Spring	1	1	1	1	1	1	2	1	4	0.063	0.750	1.000	1.000	3.000
Lens	1	1	2	1	2	1	2	1	4	0.063	0.750	1.000	1.000	3.000
Lens Holder		0	1	1	1	1	2	1	3	0.111	0.667	0.667	1.000	1.333
Metal Clip	1	1	1	1	1	1		0	3	0.111	1.000	1.000	1.000	3.000
Picture Frame	1	1	2	1	3	1	4	1	4	0.063	0.500	1.000	1.000	2.000
Shutter	1	1	2	1	2	1	3	1	4	0.063	0.500	1.000	1.000	2.000
Shutter Cover	1	1	2	1	3	1	4	1	4	0.063	0.500	0.750	1.000	1.500
Shutter Spring	1	1		0	1	1	1	1	3	0.111	1.000	1.000	1.000	3.000
Sprocket	1	1	2	1	1	1	3	1	4	0.063	0.750	0.750	1.000	2.250
Thumb Wheel	1	1	2	1	2	1	3	1	4	0.063	0.500	0.500	1.000	1.000
Top Cover		0	1	1	1	1	2	1	3	0.111	0.500	0.667	1.000	1.000
Viewfinder	1	1	2	1	2	1	3	1	4	0.063	0.500	1.000	1.000	2.000

Sum ni*f1i*fi2*f3i	46.208
Sum 1/ni^2	2.118
Number of non-differentiating parts P	24
Number of products N	4
PCI	**47.0**



(a)

(b)

Fig. 3. Examples of dissected products laid out for analysis: (a) one-time-use camera family; (b) two coffeemakers from family.

consensus on the value to enter. Finally, two more values are entered: (1) the number of non-differentiating parts, and (2) the number of products in the family. The PCI is then automatically computed, which in this case is 47.0.

During their analysis, the majority of the teams dissecting the cameras (Kodak and Fujifilm) were very systematic in laying out their products side-by-side (see Fig. 3a) even though they were not instructed to do so. This was relatively easy to do since the cameras are small and do not have many components. By comparison, the coffeemakers took up much more space to lay out their components as seen in Fig. 3b, making it more difficult to do side-by-side comparisons of the products when computing PCI.

The PCI values computed by each team for each family are listed in Table 4; the bold values indicate the first family dissected and analyzed by each team while the non-bold values indicate the PCI computed by the team for a family dissected by another team (refer to Table 2). While there is little

Table 4. Initial PCI values

Team	Mr. Coffee 1	Mr. Coffee 2	Kodak 3	Fuji 4	Kodak 5
1	**63.2**				43.1
2		**58.8**		71.5	
3			**55.3**	70.9	
4			63.3	**68.3**	
5		74.5			**41.5**

variation in the PCI values for the Fujifilm family (68.3 to 71.5), there is considerable variation in the PCI values for the Mr. Coffee coffeemakers (58.8 to 74.5) and Kodak one-time-use cameras (41.5 to 63.3). When comparing the camera families, there is consistency of the values, i.e., the PCI values for the Kodak family are always lower than the PCI values for the Fujifilm family even with the large range of variation.

After the experiment, the results were analyzed in more detail to identify the sources of these differences. We first looked at the *dissection* portion of the experiment and then the *computation* portion of the experiment, and we identified three major contributors to the variations in PCI:

1. Different levels of dissection
2. Parts omitted from analysis
3. Different values for f_{ji} factors

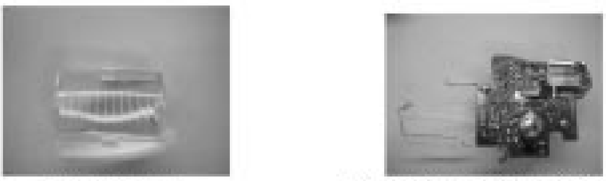
Discussion about the impact and extent of each of these contributors follows.

Different levels of dissection

Some teams dissected their products more thoroughly, which lead to more parts being identified and included in the PCI calculation. For example, the flash in the one-time-use cameras was considered as one part by several teams, while others dissected it more thoroughly to identify two distinct parts, namely, the flash cover and the flash printed circuit board (see Fig. 4). Similar variations existed among the coffeemakers, many of which included printed circuit boards and lots of wiring; some teams dissected these to a greater level of detail than others. Finally, there were also some differences in naming components for analysis, but this was not a major contributor to the differences in the PCI since it did not change the number of parts being analyzed.

Parts omitted from analysis

A much larger contributor to the variation was parts being omitted from analysis, either volunta-



Flash Cover   Flash Printed Circuit Board

Fig. 4. Example of analyzed parts for the Kodak one-time-use cameras.

rily or involuntarily. First, some teams forgot to include parts in the analysis; for example, the camera film, although obviously a major component, was (involuntarily) omitted from the analysis by one team (see Table 5). Second, teams were told to not consider parts such as screws, electrical wires, etc. since they can be easily standardized; however, some teams included these parts in their analysis while others omitted them. Finally, some parts were omitted from the analysis if the team did not dissect a subassembly to a sufficient level of detail as mentioned previously.

Consequently, before we could really interpret the results in Table 4, we had to 'standardize' the results to take into consideration the different levels of dissection and omitted parts. First, we renamed each part within each family using a common name. Second, we removed the unique parts along with screws, fasteners, etc. While the unique parts should not be considered when calculating PCI, it is also recommended not to include parts that can be easily standardized in the analysis. Finally, we added any omitted parts from a team's analysis and used the arithmetic average of the f_{ji} factors attributed by the other teams; a similar approach is used during the analysis of experimental designs when data is missing [30]. The rightmost column in Table 5 indicates the omitted parts from each team's analysis for the four Kodak one-time-use cameras.

Using the 'completed' data, each team's PCI value was recalculated, and the 'corrected' PCI values are summarized in Table 6. The percent change in the PCI value is noted to the right of the corrected PCI value in parentheses. Despite these corrections, the trends are still the same. The PCI variations are still considerable for the Mr. Coffee coffeemakers and Kodak one-time-use cameras (54.4 to 79.0 and 47.0 to 64.0, respectively), while the variation remains small in the Fujifilm one-time-use cameras (68.3 to 71.5). Now that we had mitigated the differences from *dissection*, we proceeded to investigate the differences in PCI due to the f_{ji} factors.

Differences in values for f_{ji} factors

For a given part, different teams attributed different values to the f_{ji} factors; this is the major source of variability when computing PCI. Consider the summary of the analysis of each team for the Kodak one-time-use cameras shown in Table 7. A '1' in any of the last three columns indicates that the value of that f_{ji} factor differs at least once among the four teams' analyses. As seen in the figure, factor f_{1i} has a different value for 17 out of the 24 rows (parts); f_{2i} varies 9 out of 24 rows, and f_{3i} varies 7 out of 24 rows.

Using these numbers, we can compute the ratio of the 'number of parts where the factor f_{ji} is different' to the 'total number of parts', e.g., for f_{1i} the ratio is 1–(24–17)/24 = 70.8%. Table 8 summarizes these ratios for all three families. Based on these ratios, we note that there is much less variation in values assigned to the f_{3i} factor

Table 5. Summary of omitted parts for each Kodak one-time-use camera for each team's analysis

Parts	FunSaver 35				Waterproof				Max Flash				Max Outdoor				Different parts
	Team 1	Team 3	Team 4	Team 5	Team 1	Team 3	Team 4	Team 5	Team 1	Team 3	Team 4	Team 5	Team 1	Team 3	Team 4	Team 5	
Back Cover		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Part omitted in the analysis
Battery	1	1	1	1					1	1	1	1					
Cam	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Exposure Counter Wheel	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Film		1	1	1		1	1	1		1	1	1		1	1	1	Part omitted in the analysis
Film Axle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Flash Assembly	1	1	1	1					1	1	1	1					
Flash Cover	1		1	1					1		1	1					Part forgotten (dissection not to the lowest level)
Frame	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Front Cover	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
High Energy Lever 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
High Energy Lever 2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
High Energy Lever Spring	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Lens	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Lens Holder	1	1	1	1		1	1		1	1	1	1	1	1	1	1	Part omitted in the analysis
Metal Clip	1				1			1	1			1	1			1	Part forgotten (dissection not to the lowest level)
Picture Frame	1			1				1	1			1	1			1	Part omitted in the analysis
Shutter	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Shutter Cover	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Shutter Spring	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	Part omitted in the analysis
Sprocket	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Thumb Wheel	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Top Cover	1	1	1	1		1			1	1	1	1	1		1	1	Part omitted in the analysis
Viewfinder	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	Part omitted in the analysis

Table 6. 'Corrected' PCI values

Team	Mr. Coffee 1	Mr. Coffee 2	Kodak 3	Fuji 4	Kodak 5
1	**63.8 (+0.95%)**				48.9 (+13.46%)
2		**54.4 (–7.48%)**		68.6 (–4.06%)	
3			**54.8 (–0.09%)**	72.4 (+2.12%)	
4			64.0 (+1.11%)	**65.2 (–4.54%)**	
5		79.0 (+6.04%)			**47.0 (+ 13.25%)**

Table 7. Summary of different f_{ij} factors for each Kodak one-time-use camera for each team's analysis

Parts	Size & geometry f1				Material & Manufacturing f2				Fastening & assembly f3				Different f1	Different f2	Different f3
	Team 1	Team 3	Team 4	Team 5	Team 1	Team 3	Team 4	Team 5	Team 1	Team 3	Team 4	Team 5			
Back Cover	0.25	0.25	0.25	0.50	1.00	1.00	1.00	1.00	1.00	0.75	1.00	0.75	1		1
Battery	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
Cam	1.00	1.00	1.00	0.50	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1		
Exposure Counter Wheel	0.50	0.75	0.75	0.25	1.00	0.75	1.00	1.00	1.00	0.75	1.00	1.00	1	1	1
Film		1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00			
Film Axle	0.50	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1		
Flash Assembly	0.50	1.00	0.50	0.50	0.50	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1	1	
Flash Cover	1.00		1.00	1.00	1.00		1.00	1.00	1.00		1.00	1.00			
Frame	0.25	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1		
Front Cover	0.25	0.25	0.25	0.50	1.00	1.00	1.00	1.00	1.00	0.75	1.00	0.75	1		1
High Energy Lever 1	0.75	1.00	1.00	0.75	0.50	0.50	0.50	0.50	1.00	1.00	1.00	0.75	1		1
High Energy Lever 2	0.75	1.00	1.00	0.75	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1		
High Energy Lever Spring	0.75	1.00	1.00	0.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1		
Lens	0.75	0.75	0.75	0.75	1.00	0.75	1.00	1.00	1.00	0.75	1.00	1.00		1	1
Lens Holder	0.67	0.75	0.75	0.67	0.67	0.75	1.00	0.67	1.00	0.75	1.00	1.00	1	1	1
Metal Clip	1.00			1.00	1.00			1.00	1.00			1.00			
Picture Frame	0.50			0.50	1.00			1.00	1.00			1.00			
Shutter	0.50	0.75	0.75	0.50	1.00	0.75	1.00	1.00	1.00	1.00	1.00	1.00	1	1	
Shutter Cover	0.50	0.75	0.75	0.50	0.75	0.75	0.75	0.75	1.00	1.00	1.00	1.00	1		
Shutter Spring	1.00	1.00	1.00	1.00	1.00	0.75	1.00	1.00	1.00	1.00	1.00	1.00		1	
Sprocket	0.75	1.00	1.00	0.75	0.75	0.50	0.50	0.75	1.00	1.00	1.00	1.00	1	1	
Thumb Wheel	0.50	1.00	1.00	0.50	0.50	0.75	1.00	0.50	1.00	1.00	1.00	1.00	1	1	
Top Cover	0.67	1.00	1.00	0.50	0.67	1.00	1.00	0.67	1.00	1.00	1.00	1.00	1	1	
Viewfinder	0.50	1.00	0.75	0.50	1.00	1.00	1.00	1.00	0.75	1.00	1.00	1.00	1		1
													17	9	7

Table 8. Variation in f_{ji} factors for the PCI calculation

Number of parts where the factor f_{ji} is different ÷ total number of parts	f_{1i}	f_{2i}	f_{3i}
Kodak one-time-use cameras	70.8%	37.5%	29.2%
Fujifilm one-time-use cameras	34.8%	30.4%	26.1%
Mr. Coffee coffeemakers	29.2%	37.5%	25.0%

than for either f_{1i} or f_{2i}. For the 'assembly and fastening scheme' factor, f_{3i}, the teams were able to more consistently identify the commonality of connections and the assembly of the parts with less variation. They were able to clearly compare the assembly method between two parts (e.g., glued, snap-fit, screwed).

Another observation is the high level of differences for the factor f_{1i} for the Kodak family, which is due to the teams' interpretation of what an 'identical shape and size' is. One group considered two parts with 'similar' shape and size as 'identical'. Consider the front covers shown in Fig. 5. Each camera in the Kodak family has a front cover, and all the covers have a different shape. The corresponding f_{1i} is 1/4; however, one team considered that two of the covers were 'identical' because they were very similar in size and shape, and they assigned f_1 a value of 1/2.

For the f_{2i} factor, the differences are due to a misinterpretation of what an 'identical material' is. Some teams considered that two parts made of the same material (such as plastic) but with different colors (such as black for one and blue for the other) are still 'identical material', while other teams considered these parts different. Such a part is illustrated in Fig. 6.

In summary, the differences between the f_{ji} values arose primarily from a lack of precise and accurate definitions of terms. The term 'identical' was interpreted differently by each group, resulting in large variations in the PCI value due to the values assigned to the f_{ji} factors. In future experiments, a more complete definition of each factor should be given to minimize these variations when computing the PCI.

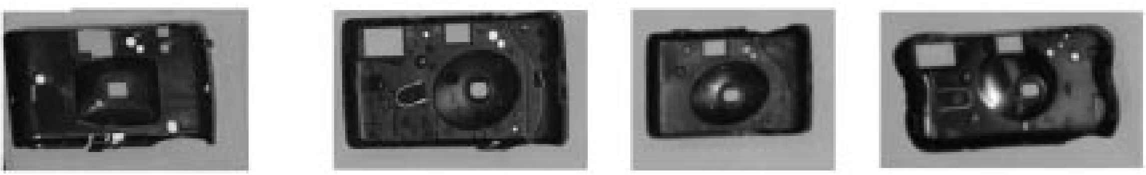


Fig. 5. Front covers for the Kodak one-time-use cameras.

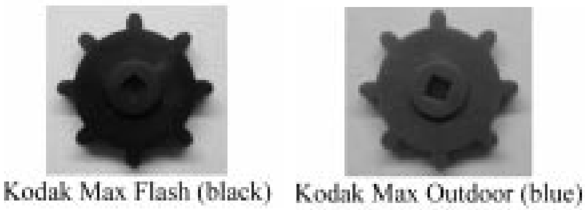


Fig. 6. Example of a 'similar' part in the Kodak one-time-use camera family.

ASSESSMENT OF STUDENT LEARNING

At the end of the semester, students were asked to complete a five-item questionnaire (see Table 9) to evaluate their understanding of commonality before and after the product dissection activity. Each item was rated on a 7-point Likert type scale, with 1 being the lowest and 7 being the highest. Twenty-four students completed the questionnaire. Before the in-class activity, students rated their own understanding of commonality an average of 4.08 out of 7; after the activity, this rating was 6.00 out of 7, on average. A two-tailed dependent t-test of the response means before and after the in-class activity for these two items showed significant differences ($p < 0.001$) in the predicted direction, that is, students' self-reported understanding of commonality within a family of products increased as a result of this activity. In future experiments, we plan to administer a short quiz before and after the experiment to provide a more objective measure of students' understanding of commonality in addition to the self-reported assessment.

The students felt that the activity related very well to the course objectives, giving an average rating of 6.33 out of 7 for this item. The students gave an average overall rating of 6.29 out of 7 to this in-class activity when compared to other in-class activities. When asked how well they still remembered this activity at the end of the semester, students rated it an average of 6.29 out of 7, indicating good retention of the activity itself, and hopefully the lessons learned from it. In feedback received at the end of the semester, one student wrote, 'I liked the dissection of the Kodak single-use camera' and another student suggested, 'It would be interesting if one team dissects competing products (e.g., Kodak and Fuji) and compares the range of PCI for each.' As can be seen in Table 2, only two teams had this opportunity, but the time spent working on the activity could easily be increased in the future to accommodate such comparisons more.

CLOSING REMARKS

Product dissection has been used to significantly increase students' understanding of platform commonality within a graduate course involving mechanical engineering and industrial engineering students. The product dissection activity described in this paper is unique in that students dissect *multiple* products from a single family rather than a single product as is typically done in undergraduate product dissection courses. This activity rates highly among the in-class activities used in this course and provides an interactive and fun way to actively engage students in their learning.

The product dissection was also used to integrate product family design research into the classroom by having students participate in a study to evaluate the variability in the Product Line Commonality Index (PCI). Based on their results, we identified three main sources of the variability that occur during the dissection of the products and calculation of the PCI: different levels of dissection, parts omitted from the analysis, and different values for the factors used to compute the PCI. Examples of each were discussed using the results from the four Kodak one-time-use cameras.

There are several implications based on these findings. First, variations that occur during *dissection* can be reduced by making sure that each team dissects their products to the same level, and specific rules should be used to define this. For example, a part could be considered one element if it is made of one material. For the parts that are hard to dissect, rules for leaving them as subassemblies should be given, for example, electronic printed circuit boards are always considered as one element. Finally, a detailed parts list would be helpful to ensure that parts are named properly and minimize the omission of parts from the analysis.

During the *calculation* of PCI, detailed definitions should be included for the different factors, and these rules should be systematically applied by each team. For example, a list of possible assembly and fastening schemes could be established for the f_3 factor. Teams could then pick from this list when deciding how parts were assembled and fastened

Table 9. Self-reported assessment of product dissection activity.

Assessment Question (7-point Likert Scale with 1=low and 7 = high)	Mean	Std. Dev.
Rate your understanding of commonality before the exercise.	4.08[a]	1.35
Rate your understanding of commonality after the exercise.	6.00[a]	0.93
Rate the relationship between this exercise and the course objectives.	6.33	0.82
Rate how well you still remember this activity.	6.29	1.12
Overall rating of this in-class activity.	6.33	0.87

[a] $p < 0.001$ for two-tailed dependent t-test for differences between before and after mean

together. By creating specific rules, the variability of the PCI can be greatly reduced to provide a more repeatable and accurate measure of platform commonality for use during product family design.

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