Session XXXX

An Inter-University Collaborative Undergraduate Research/Learning Experience for Product Platform Planning

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Abstract

Product Platform Planning is an emerging philosophy that calls for the planned development and deployment of families of related products. It is markedly different from the traditional product development process, which focuses on optimized designs for individual products. Product family planning places a much higher demand on management of information of multiple types and from multiple sources. In response, researchers at four universities are collaborating on the development of an information technology infrastructure to support product platform planning. This is a relatively new development in engineering design that is typically not part of the undergraduate education; therefore, we see an intrinsic relationship between the need for integrating the development of research directly with educational enhancements to teach students about these concepts. This paper describes an undergraduate research/learning experience where students from each of the participating institutions worked collaboratively in support of the overall research project. To enhance the students' education, they spent several weeks in a focused experience at two of the universities with visits to the others. The intent was to broaden their perspectives on the operations at different schools and promote interest in graduate school while learning about product platform planning. We describe the structure of the program along with the activities undertaken by the students. We also include an assessment of the program by the students and plans for improving our future offering of this program.

Nomenclature

BOM	Bill of Materials
DSM	Design Structure Matrix
EBOM	Enhanced Bill of Materials
FCM	Function-Component Matrix
JSP	Java Server Pages
ITR	Information Technology Research
PSU	Penn State University
PVM	Product Vector Matrix
REU	Research Experiences for Undergraduates
UMR	University of Missouri-Rolla
WCN	Weighted Customer Needs

1. Introduction

Product Platform Planning is an emerging philosophy that calls for the planned development and deployment of families of related products. It is markedly different from the traditional product development process, which focuses on optimized designs for individual products. Designing a product platform and corresponding family of products is a difficult task that embodies all of the challenges of product design while adding the complexity of coordinating the design of multiple products in an effort to increase commonality across the set of products without compromising their individual performance (i.e., distinctiveness). Simpson[1] provides an extensive review of the flurry of research activity that has occurred in product platform and product family design and optimization in the past decade.

Regardless of whether the platform is modular or scalable, the basic development strategy within any product family is to leverage the product platform across multiple market segments or niches[2]. Companies like Sony[3], Volkswagen[4], and Black & Decker[2] have successfully employed product platform strategies to increase product variety while reducing development costs, manufacturing costs, and time-to-market. By sharing assets such as components, processes and knowledge across a family of products, companies can efficiently develop differentiated products and increase the flexibility and responsiveness of their product realization process. As such, product platform planning places a much higher demand on management of information of multiple types and from multiple sources to exploit the potential of shared assets.

In an effort to address many of these research challenges, five faculty at four universities—Penn State University (PSU), University of Missouri-Rolla (UMR), Bucknell University, and Virginia Tech—are collaborating on medium-sized Information Technology Research (ITR) Grant from the National Science Foundation to develop an information technology infrastructure to support product platform planning and customization[5]. We recognize that this is a relatively new development in engineering design that is typically not part of the undergraduate education; therefore, we see an intrinsic relationship between the need for integrating the development of research directly with educational enhancements to teach students about these concepts.

The remainder of this paper describes an inter-university undergraduate research/learning experience where one student from each of the participating institutions worked collaboratively in support of developing an information technology infrastructure for product platform planning. To enhance the students' education, they spent several weeks in a focused experience at two of the universities (PSU and UMR). The intent was to broaden their perspectives on operations at different schools and promote interest in graduate school while learning about product platform planning. After a brief review of related literature in the next section, we describe the structure and implementation of the REU (Research Experiences for Undergraduates) program along with the activities undertaken by the students in Section 3. An assessment of the REU program based on student comments and feedback is discussed in Section 4. Closing remarks and plans for improving our future offering of this REU program are given in Section 5.

2. Literature Review: Product Dissection and the UMR Design Repository

Few would argue that engineers are more likely to be active rather than reflective learners[6], and the benefits of "hands-on" educational 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)[7]. It has also been used to help teach competitive assessment and benchmarking[8,9]. 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[10]. Sheppard[11] was among the first to develop a formal course in product dissection at Stanford University (http://www-adl.stanford.edu/), and a similar course in product dissection was developed as part of the Manufacturing Engineering Education Partnership between Penn State, University of Washington, and University of Puerto Rico-Mayaguez[12]. Product dissection has also been used, with varying degrees of success, in conjunction with multimedia case studies at Berkeley[13], Stanford[14], and Penn State[15].

Through dissection, students are able to identify firsthand how different companies have resolved the inherent tradeoff between commonality and distinctiveness within a product family discussed in Section 1. 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 Figure 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[4,16], but as word spread about their platform strategy, customers started buying lower-end models instead of the higher-end ones, which decreased their profitability[17]. Volkswagen has since announced plans to overhaul their image, particularly their high-end Audi brand, to distinguish the individual brands more from each other[18,19]. Other examples can be found in a recent review of product platform design strategies[20].

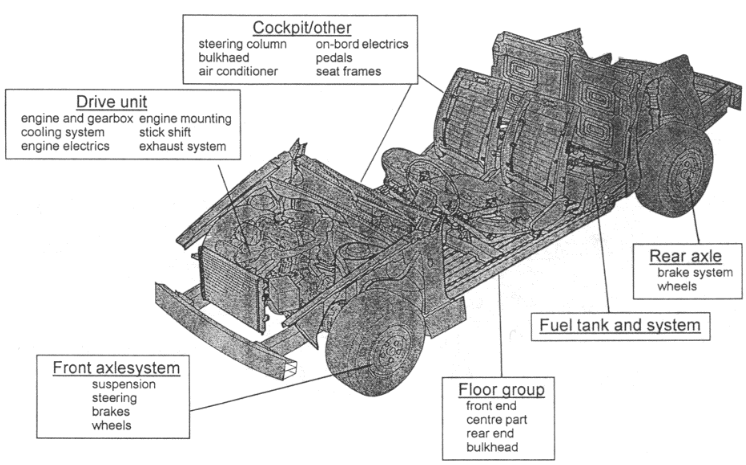


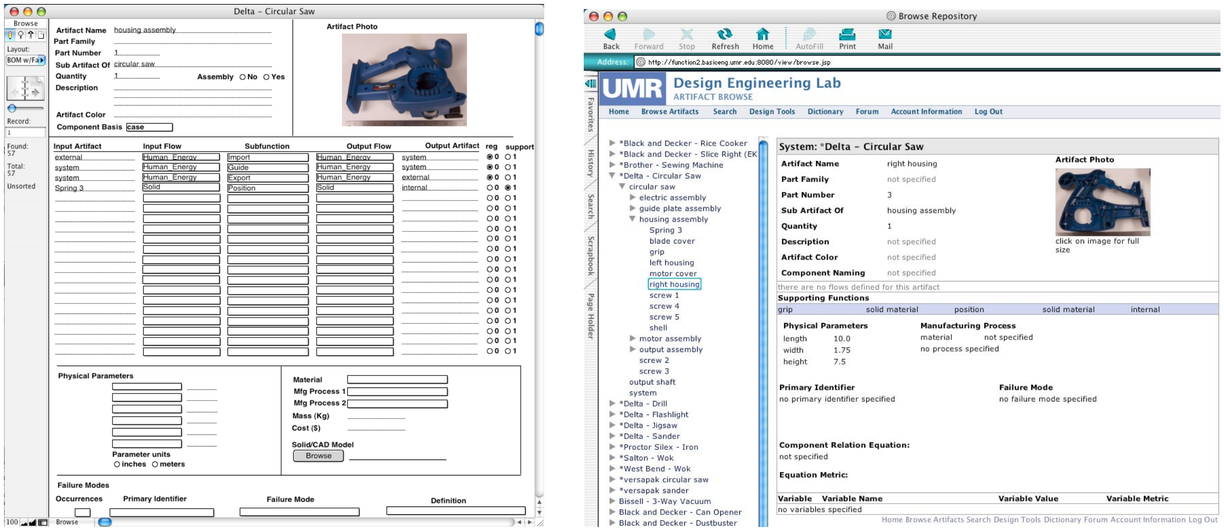
Figure 1. Volkswagen's Platform Definition[21]

While examples like that of Volkswagen are useful in conveying the merits (and potential drawbacks) of platform commonality, few engineers have a true appreciation for the extent to which different companies utilize platform commonality within their products. Many are flabbergasted when they learn that 80-90% of the non-differentiating components in a Sony Walkman® are common[22] and that 250+ models have been created from only three basic Walkman® platforms[3]. 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[23,24], there is much to be gained in pairing product dissection with learning about product platforms and product family commonality. Product dissection was a key aspect of the REU program as described in the next section, and it provided a great opportunity to populate the design repository at UMR that is at the core of our research.

A design repository is a collection of data and information that is intended to aid in the creation of new products[25]. The data and information compiled in a design repository is not stagnant but is used dynamically. This information may include, but is not limited to, product dissection and functional descriptions of existing products that are then used in the design of new products. These repositories enable the divulgement of data to support representation, capture, sharing, and reuse of corporate and general design knowledge[25]. To date, design repository research at UMR has pursued two lines of investigation. First, ongoing research is geared toward the development of theories that explain the underlying elements and relationships for representing designs. The second line of work uses mature concepts from these theories and implements them in a computational web-based framework that is designed for interactive search. Both of these thrusts are in place to support the underlying goal of providing a comprehensive description of designs in a repository that can be used to improve design synthesis and analysis.

Initial efforts for the UMR repository were based on the National Institute of Standards and Technology Core Product Model, including Artifact, Function, Transfer Function, Flow, Form, Geometry, Material, Behavior, Specification, Configuration, Relationship, Requirement, Reference, and Constraint[26]. Recent progress has established the concept of an Enhanced Bill of Materials (EBOM) that handles entry, management and export of repository knowledge[27]. All design knowledge corresponds to a single artifact (which may itself be composed of additional subartifacts). The EBOM concept is implemented in a database using FileMaker Pro. A partial screenshot of the interface of FileMaker is show in Figure 2(a). Following entry and storage into FileMaker, a platform-independent data set is output as XML. By creating JSP (JavaServer Pages), the XML from the database server can be viewed as HTML through a standard web browser[27-29] as shown in Figure 2(b).

We are currently extending the design repository research through our ITR grant by focusing on design artifact information rather than information on design guidelines, heuristics, or design processes (http://function.basiceng.umr.edu/repository). The design repository is currently implemented as a web-based application. In this format, we recognize the important role of designing a web interface for a knowledge database where emphasis is given toward Human Computer Interaction issues. Ongoing research is geared toward identifying the hurdles of merging design theory and software design techniques and to formulate a usable software interface to meet the needs of designers[29].



(a) (b)

Figure 2. (a) FileMaker Input Screen and (b) UMR Design Repository Web Interface

As a summary of the current web-based system, three main interaction modes of use are supported: browse, search, and process design tool output. In the browse mode as shown in Figure 2(b), artifacts in the repository can be selected on the left pane and inspected on the right. The search mode allows the user to search for all artifacts that match an input selection. The final mode of operation includes the execution of certain design tools including the function-component matrix, design structure matrix, bill of materials, and soon to be implemented functional model and parametric model outputs. The REU program described in the next section sought to capitalize on the recent developments in the design repository while expanding the scope of the products (artifacts) captured within the repository.

3. Implementation and Structure of the REU Program

In order to take full advantage of the multiple institutions involved in our ITR collaborative research grant, we requested one REU supplement for each of our four partner institutions, which allowed us to hire four REU students for Summer 2004. Students spent four weeks working at PSU (the better part of June) and then four weeks working at UMR (July and early August). Students were given a weeklong break during the July 4th weekend so that they could visit family and friends or return home to their respective schools briefly before going to UMR. The students coordinated their respective travel plans so that they all flew into St. Louis, MO (the nearest airport to UMR) the same afternoon and arranged for the REU student from UMR to provide transportation from the airport to UMR. At the end of the REU program, the faculty working on the ITR grant all met at UMR to listen to the REU students give a group presentation that described what they had accomplished during their time at PSU and UMR. Figure 3 shows a picture of the students and faculty involved in the REU program as we posed for a picture that was to be used in an upcoming article in *IE Magazine* that discussed our research work.

Figure 3. Faculty and Students from the REU Program Pose for a Picture for *IE Magazine*

Housing at both PSU and UMR were provided through summer housing programs that were being run by the respective schools, and some of the REU funds were allocated to cover housing and travel expenses. In particular, $4000 went directly to each student, $500 was pooled from each student to pay for housing and travel expenses, and the remaining $1500 was taken as overhead by each institution. Any remaining expenses for housing and travel, excluding food, were paid for with funds from the ITR grant at the host institutions (PSU and UMR). In Summer 2005, Bucknell and Virginia Tech will host the REU program, and they will cover any extra expenses for the REU students.

During the eight week period, students spent the majority of their time dissecting and analyzing 17 products from three different product families: the Delta ShopMaster® cordless toolset and the Black & Decker Firestorm® and Versapack® cordless toolsets. These product families were selected based on availability, price, and the interests of the REU students (i.e., they could choose between different sets of power tools, coffee makers, single-use cameras, etc., and they decided to dissect and analysis all of the power tools). While working on different sets of power tools reduced the number of different types of products that the students might have dissected, it did allow for good consistency in data capture since many tools were similar across the product families (e.g., all three tool sets have a drill, circular saw, and flashlight). To help demonstrate the dissection, analysis, and data capture steps that the REU students performed for each product in the family, examples from the Firestorm® drill accompany a brief description of each step.

Step 1 – Dissect the product to the lowest level possible: Students were instructed to take apart each product as best as possible, leaving sub-assemblies such as motors and trigger mechanisms intact for analysis. Students familiarized themselves with the reverse engineering methodologies of Otto and Wood[30] and practiced dissection on a series of test products (e.g., drill, coffee maker, and single-use camera) before starting their formal analysis of the products in any of the families. Two students also had experience with product dissection prior to this program: the REU student from UMR had worked closely with graduate students in Dr. Stone's lab on the design repository and the REU student from PSU had taken a course in product dissection with Dr. Simpson (see http://www.mne.psu.edu/simpson/courses/me288/).

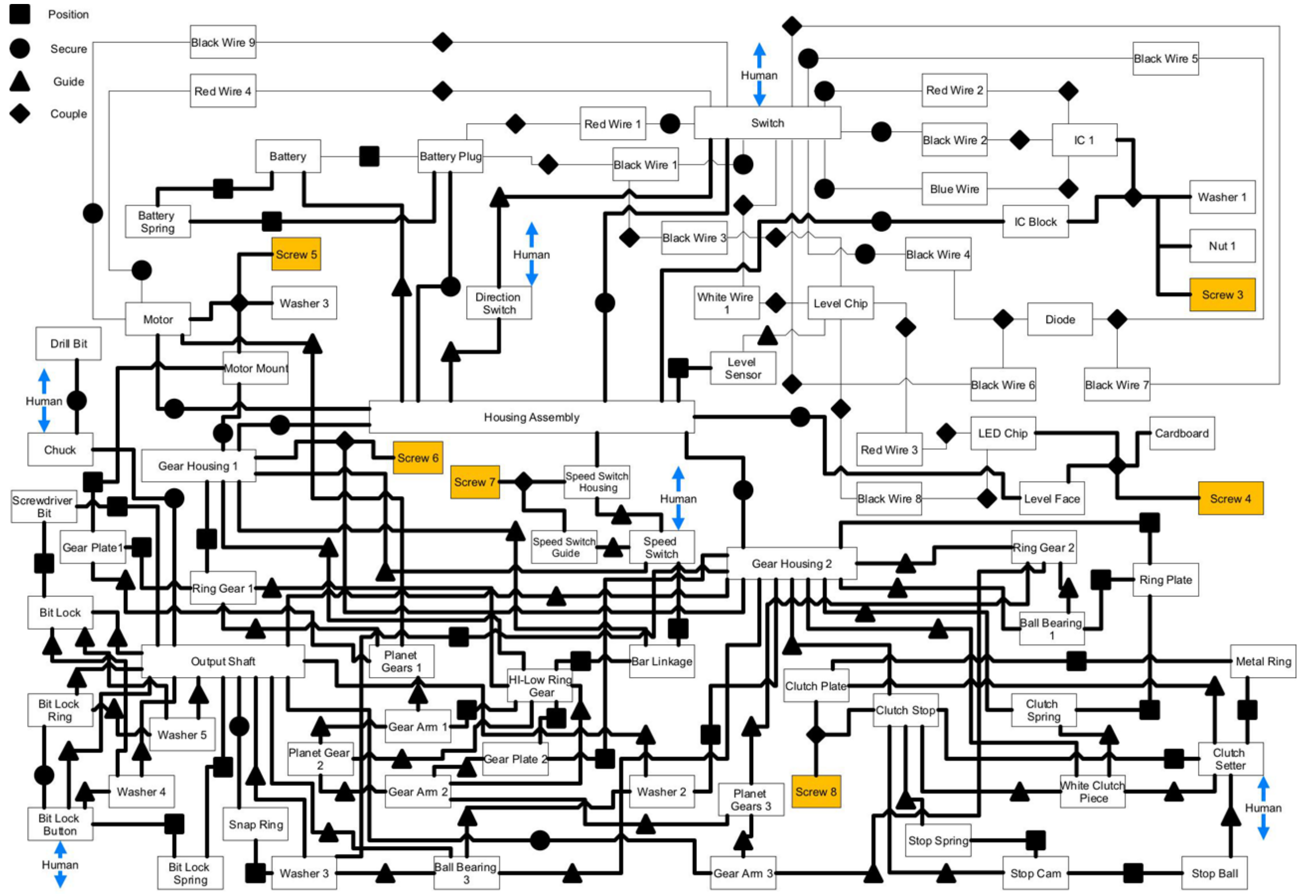


Figure 4. Example Assembly Diagram

Step 2 – Create an assembly diagram of the product: Once the product was dissected, students created an assembly diagram of the product using Concept Draw V, a graphing and drawing package available for both Macintosh and Windows (http://www.conceptdraw.com/). Our hope was that having the students create an assembly diagram immediately after dissecting the product would increase the chances of them reassembling the product after analysis, which they were able to successfully accomplish. The assembly diagram for the drill is shown in Figure 4. Each assembly diagram includes a key to indicate how connections are made.

Step 3 – Create a function structure model for the product: After creating an assembly drawing, the students created a function structure model for the product to describe, in a form-independent manner, how the product functions. They used the functional basis that is being developed by Stone and his colleagues[31,32]. The input, output, material and energy flows, and functions for the drill are shown in Figure 5. This was also created using the software package Concept Draw V.

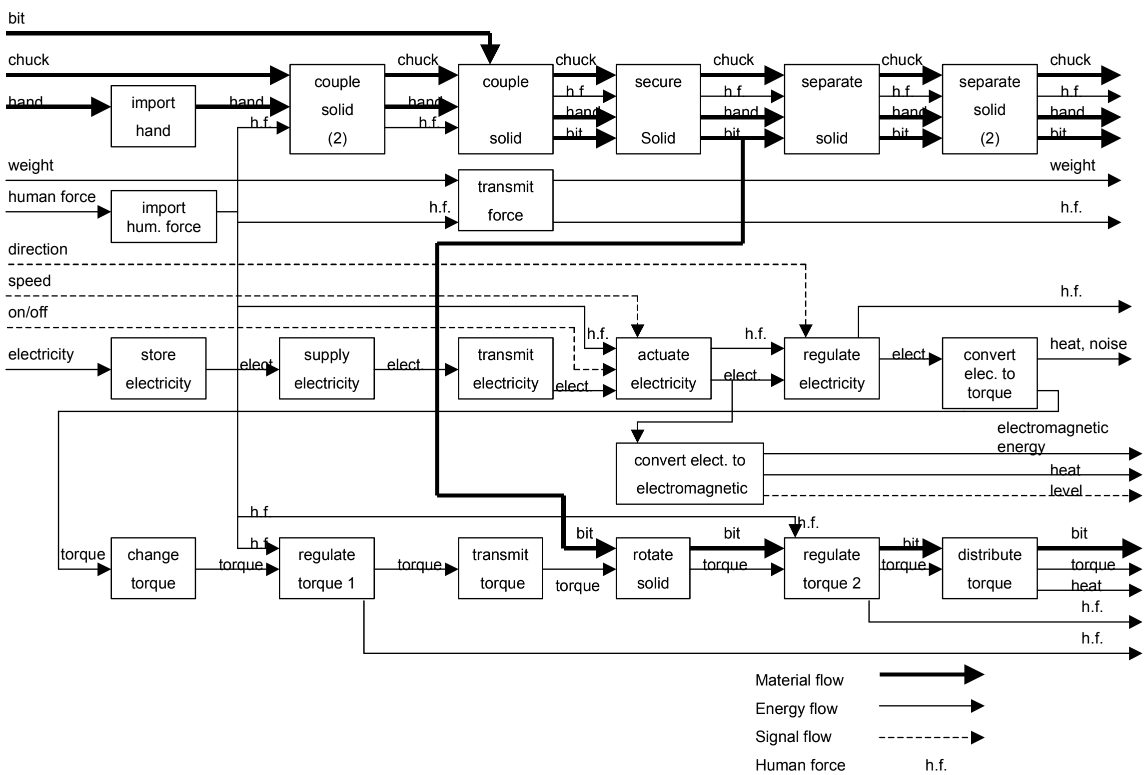


Figure 5. Example Function Structure Model

Step 4 – Complete repository entry files for the product: The remainder of the analysis for the product consisted of completing the enhanced Bill of Material (EBOM) representation for the design repository at UMR [33]. To facilitate this process, a template has been created using the Filemaker Pro software package (http://www.filemaker.com), which is available for both Macintosh and Windows machines. The template provides forms for creating each of the following files and matrices:

- *Bill of Materials* (BOM): The BOM lists of all the components in the product, including information for the material, manufacturing process, weight, overall dimensions of each component and picture of each component. Figure 6 shows the BOM for the drill, and Figure 7 shows pictures of the components and sub-assemblies in the drill.

- *Design Structure Matrix* (DSM): The DSM shows the interactions between components where a 1 represents a connection and a blank indicates no connect. The DSM for the drill is shown in Figure 8.

Part #		Qty.	Part Name	Function (Sub-fct. description from fct. model)	Mass (g)	Finish	Color	
Assembly ID	Part ID							Material
1	1	1	Battery	store/supply electricity	720.0	smooth, dull	Black	Metal/Plastic
2	2	1	Chuck subassembly	couple solid/couple solid (2)/secure solid/separate solid/separate solid (2)/import hand	224.5	smooth, dull	Black	Plastic
3	3	6	screws (6) 4small,2large	transmit force	1.0	plated	Black	Metal
4	4	1	circular metal bracket (w/ 4 prongs)	couple solid (2)/separate solid (2)	0.4	smooth, bright	Silver	Metal
5	5	1	metal pin (looks like a staple)	couple solid (2)/separate solid (2)	0.0	smooth, bright	Silver	Metal
6	6	1	orange plastic "support"	couple solid (2)/separate solid (2)	3.8	smooth	Orange	Plastic
7	7	1	smaller metal washer	couple solid (2)/separate solid (2)	0.0	smooth, bright	Silver	Metal
8	8	1	larger metal washer	couple solid (2)/separate solid (2)	0.3	smooth	Grey	Metal
9	9	1	spring	couple solid (2)/separate solid (2)	0.8	smooth, bright	Silver	Metal
10	10	2	screw (2) smaller	regulate torque2	0.7	plated	Black	Metal
11	11	1	large metal cap plate	regulate torque2	20.7	smooth, plated	Black	Metal
12	12	1	large metal "hoop"	regulate torque2	0.2	smooth	Grey	Metal
13	13	1	clutch subassembly	regulate torque2	40.5	smooth, dull	Black/White	Plastic/Metal
14	14	1	larger metal spring	regulate torque2	15.0	smooth, bright	Gold	Metal
15	15	1	large metal hoop	regulate torque2	4.1	smooth, plated	Gold	Metal
16	16	12	ball bearing (12)	regulate torque2	0.5	smooth, bright	Silver	Metal
17	17	1	right cover	transmit force/import human force/distribute torque	120.2	smooth, dull, rubber grip	Orange	Plastic
18	18	2	Small pin	transmit force	0.0	smooth	Black	Metal
			Large pin	transmit force	0.0	smooth	Black	Metal
19	19	1	level subassembly	convert elect. to electromagnetic	5.1	dull	Black	Plastic
20	20	1	switch subassembly	transmit/actuate/regulate elect.	60.4	smooth	Black	Plastic
21	21	1	motor/drive train subassembly	convert elect. to torque/change torque/transmit torque/rotate solid	500.0	dull	Silver/White	Metal
22	22	1	torque/ speed choice subassembly	change torque/regulate torque1	15.9	smooth	Orange/Black	Plastic
23	23	1	battery plug-in subassembly	transmit electricity	14.0	smooth, dull	Black	Plastic
24	24	1	left cover	transmit force/import human force/distribute torque	134.3	smooth, dull, rubber grip	Orange	Plastic

Figure 6. Example Bill of Materials (BOM)

- *Function-Component Mapping Matrix* (FCM): This matrix maps the relationships between the functions captured in the function structure model (see Figure 5) and the components listed in the BOM. The top row of the DSM is merged with the functions listed in column form, and the matrix is populated accordingly. The FCM for the drill is shown in Figure 9.
- *List of Weighted Customer Needs* (WCN): The customer needs for each product are ascertained through web searches, advertisements, and store displays, and represent our "best guess" as to the desired selling features for the product. Each customer need is then weighted on a scale of 1-5 (1 = low, 5 = high) to indicate its importance to the overall product. An example is shown in Figure 10 for the drill. In future offerings, we hope to work directly with a company and its products to ascertain customer needs and their associated weights more directly.
- *Product Vector Matrix* (PVM): The PVM maps the relationship between the functions listed in the function structure model (see Figure 5) and the weighted customer needs. The first column of the function-component matrix (FCM) is taken as the first column in the PVM, and the weighted customer needs are listed across the top row of the PVM. For each function that impacts a particular customer need, a '1' is entered into the cell in the matrix. The entries in each row are then multiplied by the weights of the customer needs

and totaled to create the product vector shown as the last column of the PVM. The product vector indicates the relative weighting of each function based on the customer needs. Figure 11 shows the PVM for the drill.

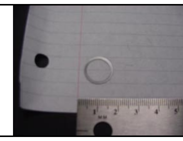
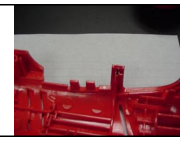
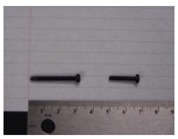
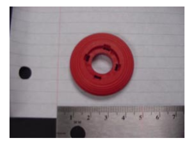
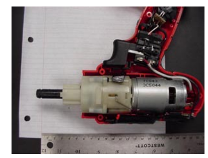
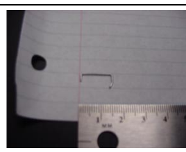
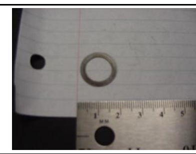
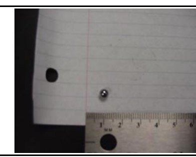
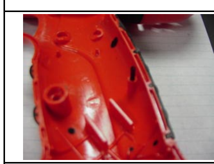
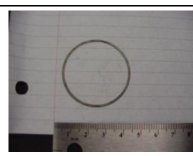
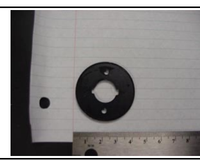
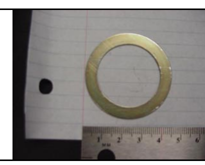
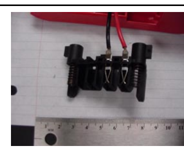
Torque-speed choice subassembly	Switch subassembly	Small spring	Small metal washer	Small metal pin
				
Screws (6)	Screw (2) smaller	Right cover	Orange plastic support	Motor-drive train subassembly
				
Metal pin looks like staple	Level subassembly	Left cover	Large metal washer	Ball bearing (12)
				
Large metal pin	Large metal hoop	Large metal cap plate	Large flat metal hoop	Clutch
				
Circular metal bracket (w/ 4 prongs)	Chuck subassembly	Battery plugin	Large metal spring	Battery
				

Figure 7. Example Pictures of Components and Sub-Assemblies

DSM	Battery	Chuck subassembly	screws (6) 4small,2large	circular metal bracket (w/ 4 prongs)	metal pin (looks like a staple)	orange plastic "support"	smaller metal washer	larger metal washer	spring	screw (2) smaller	large metal cap plate	large metal "hoop"	clutch subassembly	larger metal spring	large metal hoop	ball bearing (12)	right cover	Small pin	Large pin	level subassembly	switch subassembly	motor/drive train subassembly	torque/ speed choice subassembly	battery plug-in subassembly	left cover
Battery	1																1							1	1
Chuck subassembly		1				1								1								1			
screws (6) 4small,2large			1														1								1
circular metal bracket (w/ 4 prongs)				1	1	1																			
metal pin (looks like a staple)				1	1	1																1			
orange plastic "support"		1		1	1	1	1															1			
smaller metal washer						1	1	1														1			
larger metal washer							1	1	1													1			
spring								1	1													1			
screw (2) smaller										1	1		1												
large metal cap plate										1	1	1	1												
large metal "hoop"											1	1	1												
clutch subassembly										1	1	1	1	1											
larger metal spring		1											1	1	1										
large metal hoop														1	1	1									
ball bearing (12)															1	1						1			
right cover	1		1														1	1	1	1	1	1	1	1	1
Small pin																	1	1							1
Large pin																	1		1						1
level subassembly																	1			1	1				1
switch subassembly																	1			1	1	1		1	1
motor/drive train subassembly		1			1	1	1	1	1							1	1				1	1	1		1
torque/ speed choice subassembly																	1					1	1		1
battery plug-in subassembly	1																1				1			1	1
left cover	1		1														1	1	1	1	1	1	1	1	1

Figure 8. Example Design Structure Matrix (DSM)

Function\Component (List functions in first column, components in first row and then their interaction in the matrix)	Battery	Chuck subassembly	screws (6) 4small,2large	circular metal bracket (w/ 4 prongs)	metal pin (looks like a staple)	orange plastic "support"	smaller metal washer	larger metal washer	spring	screw (2) smaller	large metal cap plate	large metal "hoop"	clutch subassembly	larger metal spring	large metal hoop	ball bearing (12)	right cover	Small pin	Large pin	level subassembly	switch subassembly	motor/drive train subassembly	torque/ speed choice subassembly	battery plug-in subassembly	left cover
actuate electricity																					1				
change torque																						1			
convert electricity to electromagnetic energy																				1					
convert electricity to torque																						1			
couple solid		1																							
couple solid2		1		1	1	1	1	1	1													1			
distribute torque																	1								1
import hand		1																							
import human force																	1								1
regulate electricity																					1				
regulate torque1																							1		
regulate torque2										1	1	1	1	1	1	1						1			
rotate solid																						1			
secure solid		1																							
separate solid1				1	1	1	1	1	1													1			
separate solid2		1																							
store electricity	1																								
supply electricity	1																								
transmit electricity																					1			1	
transmit force			1															1	1						
transmit torque																						1			

Figure 9. Example Function Component Mapping (FCM)

Customer Need	Weight
keyless chuck	4
adjustable clutch	5
circular action (torque)	5
forward/reverse option	5
weight	4
ease of use/handling	4
battery life	4
safety	4
affordability	3
appearance	2
durability	4
level	5
speed/torque choice	5

Figure 10. Example Weighted Customer Needs (WCN)

Drill	Customer needs													
Function	keyless chuck	adjustable clutch	circular action (torque)	forward/reverse option	weight	ease of use/handling	battery life	safety	affordability	appearance	durability	level	speed/torque choice	Sum (Product vector)
CN weight –>	4	5	5	5	4	4	4	4	3	2	4	5	5	
actuate electricity					1	1			1	1	1	1		22
change torque			1		1				1		1			16
convert electricity to electromagnetic energy					1	1			1	1	1	1		22
convert electricity to torque			1		1		1		1		1			20
couple solid	1				1	1		1	1	1	1			25
couple solid2	1				1	1		1	1	1	1			25
distribute torque					1			1	1	1	1			17
import hand	1				1	1		1	1	1	1			25
import human force					1	1		1	1	1	1			21
regulate electricity				1	1	1			1	1	1			22
regulate torque1					1				1	1	1		1	18
regulate torque2		1			1	1			1	1	1			22
rotate solid					1	1		1	1		1			19
secure solid	1				1	1		1	1	1	1			25
separate solid1	1				1	1		1	1	1	1			25
separate solid2	1				1	1		1	1	1	1			25
store electricity					1		1		1	1	1			17
supply electricity					1		1		1	1	1			17
transmit electricity					1		1	1	1		1			19
transmit force					1	1		1	1	1	1			21
transmit torque			1		1				1		1			16

Figure 11. Example Product Vector Matrix (PVM)

Step 5 – Populate the design repository at UMR with the product information: Once all of the files and diagrams were created for each product, graduate students working on the design repository at UMR checked each file for completeness and correctness before it was entered into the design repository at UMR. While this process is not error proof, it does provide sufficient consistency within and across the families of products for subsequent use of the data.

A side benefit of the REU program was getting direct user feedback as the REU students worked with the repository. The REU students were instructed to provide feedback on any or all steps of the process. Suggestions included:

- Enriching the input and output flows in the repository to capture more data (e.g., specify a voltage or capacity (amp-hours) for an electrical flow or a gear ratio for a gear-gear connection).
- Enriching cost information as well, allowing more fields to enter prices based on unit count (e.g., 100 @ $1 or 5 @ $3).
- Providing a means to capture higher-level product information to help distinguish products within a family.

- Using multiple views (pictures) to better capture all aspects of an artifact rather than taking only a single picture (see Figure 7).
- Creating a common way to orient each artifact when it is being photographed so that dimensions can be more easily and consistently ascribed to it.
- Increasing the nature and types of connections in the assembly diagrams (see Figure 4) to show conditional and complex relationships and interactions, which may change during operation.
- Using different colors to more easily identify sub-assemblies within an assembly diagram, especially as they get bigger and more detailed.
- Changing the Filemaker Pro templates to include:
    - more blank fields for entering information in the artifact flow section,
    - larger text boxes to make it easier to read the text as it is being entered, and
    - an expanded component basis[34] that is provided in the drop-down list.
- Formalizing an approach to divide sub-assemblies during dissection to reduce the subjectivity involved in interpretation.

With the exception of the last bullet, all of these suggestions have been incorporated into recent enhancements and updates to the design repository and Filemaker Pro templates. This user feedback from the REU students was very helpful in directing some of our recent research efforts with the design repository and product data, which are described in Section 5. Meanwhile, student feedback on the REU program itself is provided in the next section.

4. Evaluation and Student Feedback

All four students rated their overall experience with the REU program a 5 on a 5-point Likert-type scale (1 = low, 5 = high). When asked what attracted them to our REU program, the students responded with the following reasons.

- Getting a chance to work collaboratively with students/faculty from other schools
- Having a thorough opportunity to see what other schools have to offer as far as facilities and programs (e.g., PSU's Factory for Advanced Manufacturing (FAME) lab and UMR's design programs like Formula SAE)
- Experiencing the type of work that graduate school involves
- Gaining insight about the way universities interact with industry
- Getting ideas about future areas of interest by seeing the research projects of various graduate students
- Having the chance to do some traveling to other parts of the country
- Obtaining an in-depth understanding in the functionality of the components in modern product design
- Having a summer job with good pay
- Gaining experience in working with other researchers across the U.S.

The students found the REU program "exciting because the research was in a relatively new area of engineering" and "a good opportunity to apply our education to solving problems that exist in the real world". One student stated wrote that, "This summer was one of my most productive summers ever….it was not only productive in the valuable research experience I gained, but also in the new friends I was able to make and the fun we had." All of the students felt that it was invaluable to work with peers from other intuitions. They enjoyed being able to work on their own as well as with "a group at the same level of education within a working environment that helped develop my team-work and problem solving abilities." Other valuable experiences arose from learning how to "adapting to others' work habits" and "giving me opportunities to take a leadership role within the group". Working with others "helped make the time away from friends and family easier" and was "was probably my favorite part of the whole experience". One student commented that, "it was also great to get to know them all on a social level. It made working with them much more enjoyable and satisfying". They also enjoyed having a flexible schedule so that they could "work at night or weekends" and spend time during the day exploring the campus and surrounding environment.

For all four students, the REU program increased their interest in graduate school and was "very valuable for making decisions about grad school, as well as a good way to make contacts at other schools". One student wrote, "it made me consider graduate school which I did not have much interest in before". In fact, all three graduating seniors are now applying to graduate schools, including our partner institutions. They commented that the REU program gave them an opportunity to "experience the type of work a graduate student does" and learn about "what kind of activities were involved in research". This "increased my interest in research substantially," according to one student, while another stated: "My REU experience changed my opinion about research and graduate school greatly. I had originally planned to go right into industry after I graduated, yet after having the opportunity to talk and work with professors and graduate students on a really close level, it made me want to at least get my masters." Another student enjoyed the experience so much that he commented, "After seeing some of the many research possibilities there are and having experienced some myself, I am giving some serious thought to becoming a professor in the hopes of creating my own research projects." Finally, one student wrote that the real value of the program was in providing "an opportunity to decide if I was interested [in research] before I committed to going to graduate school. I found that I would definitely be interested in going to grad school and participating in research projects, but the value of the program came from giving me the means to make that decision". As such, the REU program was "definitely a good way to recruit grad students".

Another goal of the REU program was to increase the students' interest in design and product development, and it has been successful in doing that. One student expressed newfound appreciation for the design of products: "I was surprised how complicated the design of some of the products were, for example, the cordless power drills. Looking at how products and platforms were designed during this research, I have been noticing them in everyday products." Another student commented that he "had always been kind of turned off to the idea of designing things that weren't interesting themselves (I wouldn't want to design toasters), but while dissecting the products, I found there were interesting design solutions that made it more fun to work with (like the scotch-yoke in the reciprocating saw). It was interesting to see the different solutions of different companies applied to the same problem, all of which were sometimes different than I would have expected". Students also gained a better appreciation for the "many factors that went into a design process, including all the research and evaluation of possible concepts". They were surprised to see "active and intimate labs dedicated to product development and design" at both PSU and UMR. Through this experience, one student came to the realization that that "current engineering design problems involve lots of different teams of people all working together, not the single inventor anymore". Finally, another student said that the REU program give him the opportunity to "see that design would be something I would be interested in doing for a career", as he was struggling with determining what part of mechanical engineering he wanted to pursue.

The structure of the REU program—four weeks at PSU followed by four weeks at UMR—provided a great opportunity for the students to spend a significant portion of time at another university, which was viewed favorably by all. Students from smaller towns and universities enjoyed "staying at such a larger school" and were "surprised to see all the resources the [PSU] engineering programs have for their undergrad and graduate studies". Meanwhile, the students from the larger towns and universities enjoyed spending "time in a small college town, as opposed to dealing with an enormous campus," which was attributed, in part, to the "great host" that they had at UMR: "Jeremy took great care of us and made sure that we were never bored and had everything we needed". They were also impressed the array of "facilities that the UMR students had at their disposal" and with the "amount of money they spend on their engineering program". Students also gained a better appreciation for their own institutions: "it was interesting to see how different PSU can be during the summer", and "I was also able to see a new side to UMR. I was not aware of the facilities that were provided during the experience". One student summed it up best by saying, "There was no better way to tell if you would like to go to a particular graduate school than to spend a couple weeks working there. We were able to see much more of the schools than we would have been able to otherwise, and had better opportunities to evaluate the lifestyle offered by the location also. The program gave me the experience I needed to make an educated decision".

5. Closing Remarks and Future Work

In this paper we have described an undergraduate research/learning experience where students from our four participating institutions worked collaboratively in support of developing an information technology infrastructure for product platform planning. To enhance the students' education, they spent eight weeks dissecting and analyzing 17 products from three different product families. This information was then used to populate the design repository at UMR, which is core to our research efforts. We then described the structure of the REU program and the activities undertaken by the students. Based on feedback from the students, the REU program was successful in not only increasing their interest in design and product realization but also in attending graduate school and doing research.

The dissection, analysis, and information capture that the students performed as part of the REU program has provided a wealth of information for us to utilize in our ITR research. In fact, the results of their efforts are supporting many avenues of our current research commonality assessment and platform redesign[35], product family information capture[36], product family ontology development[37], and online learning for product platforms[38]. Their suggestions for improving the design repository and Filemaker Pro templates have been used to improve the usability and streamline the data entry and capture processes.

We also received a few suggestions to improve future offerings of our REU program. Students did not entirely enjoy the "time consuming data entry, which became tedious at times," but they had a much better appreciation for what they did after visiting UMR and learning more about the design repository. They also thought that it "may be beneficial for the students to return to their respective universities to report back to their professors about what they've been doing" even though we had a group presentation with the students and faculty at UMR at the end of the program. We plan to implement these and the aforementioned changes in future offerings of the REU program.

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