2006-1623: AN INTER-UNIVERSITY COLLABORATIVE UNDERGRADUATE RESEARCH/LEARNING EXPERIENCE FOR PRODUCT PLATFORM PLANNING: YEAR 2

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Experiences with an Inter-University Collaborative Undergraduate Research/Learning Experience for Product Platform Planning

Abstract

Information management and information technology in product platform development has much untapped potential in product design. Product platforms enable the planned development and deployment of families of related products whereas a traditional design processes optimize on a single design. Product family design places an increased emphasis on management of information due to the reuse aspect of having a platform. This has prompted a multi-pronged collaborative research effort by four universities that covers many facets of the product platform realm. The National Science Foundation's Research Experience for Undergraduates (REU) Program was one of these research efforts. The REU Program gave five students from the four universities the opportunity to discover platform design and participate in ongoing research between the four universities. The students spent a month each at Bucknell University and Virginia Polytechnic Institute dissecting products designed with a platform approach and applying novel design metrics. The students worked closely with professors, post-doctoral students, graduate students, and other undergraduate students on the topic while also expanding their interests in graduate school. This paper is a reflection on the research, the structure of the REU program, and the students' overall experience. This is the second year of the program; therefore, analogies are drawn to the first year along with a follow-up on the impact to the education of the students from the first year.

Nomenclature

CDI	Commonality vs. Diversity Index
DSM	Design Structure Matrix
DSM_{flow}	Design Structure Matrix with Flow representation
ITR	Information Technology Research
PSU	Penn State University
REU	Research Experiences for Undergraduates
REUSE	Reuse Existing Unit for Shape and Efficiency
UMR	University of Missouri-Rolla
VA	Value Analysis

1. Introduction

Product Platform Planning is a design method that has been utilized by companies to reduce the cost of development and manufacturing and also expedite lead times, increasing the companies' competitiveness and success. This is possible due to the method's framework that outlines the development and deployment of families of related products. Product platform contrasts the traditional design method in that it does not try to optimize the design of a single product, rather optimize the platform in which a variety of products is based upon. The existence of a platform allows the company to introduce derivative products to new market segments, potentially increasing their market share.

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[1]. Companies like Sony[2], Volkswagen[3], and Black & Decker[1] 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.

The design of a platform and the corresponding family of products is highly complex. Product Platform Planning bears the challenges of product design in addition to the management of design of multiple products in an effort to increase commonality across the set of products without compromising their individual performance (i.e. distinctiveness). It places a much higher demand on management of information of multiple types and from multiple sources to exploit the potential of shared assets. Simpson[4] 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.

In an effort to address many of these research challenges, five faculty at four universities – Bucknell University, Virginia Tech, Penn State University (PSU), and University of Missouri-Rolla (UMR) – are collaborating on medium-sized Information Technology Research (ITR) Grant from the National Science Foundation to support product platform planning and customization[5]. They recognized that this is a relatively new development in engineering design and one that is not typically part of the undergraduate education. In response they have established a Research Experiences for Undergraduates (REU) program that integrates research and educational enhancements to teach students about these concepts.

The remainder of this paper describes an inter-university undergraduate research/learning experience from the REU program at its second year. In its first year, students from the participating institutions worked collaboratively in support of the development of an information technology infrastructure for product platform planning. In its second year, new students from the same participating institutions worked on improving and validating novel platform design metrics while using the existing information technology infrastructure developed by previous year's REU team. To enhance the students' education, they spent several weeks in a focused experience at two of the participating universities (Bucknell and Virginia Tech). 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 program along with the activities undertaken by the students in Section 3. An assessment of the REU program based on student's 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 Improving an Existing Product Family based on Commonality/Diversity, Modularity, and Cost

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[4].

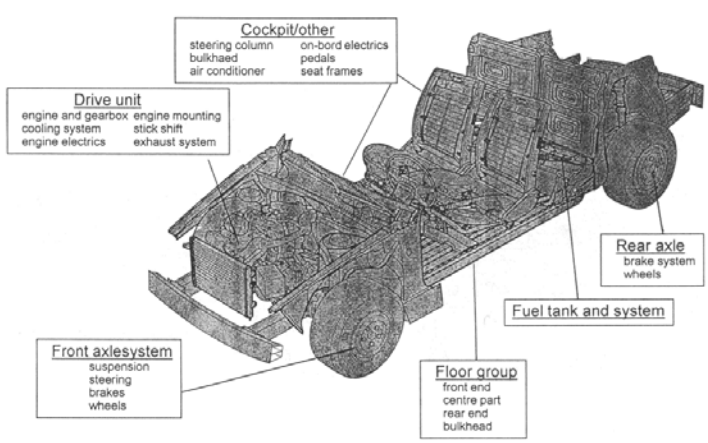

Figure 1. Volkswagen's Platform Definition[20]

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[21] and that 250+ models have been created from only three basic Walkman® platforms[2]. 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[22,23], 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 further populate the design repository at UMR. Simpson, et al.[24] discusses the UMR repository in depth as well as the REU experience during the first year.

Alongside product dissections the REU program also concentrated on new methods for improving platform design through examination of the platform's commonality/diversity, as well as its modularity and cost. A few studies have been performed focusing on these aspects. Most of the approaches to improve a platform were based on several methods, which were gathered to form a process[25]. Three categories of tools for the redesign of a family of products have been identified to be (1) The Design Specification, (2) The Module-Interface Specification, and (3) The Commonality-Diversity Specification. Each of these categories provided the respective Value Analysis (VA), Design Structure Matrix *flow* (DSM_{flow}), and the Commonality versus Diversity Index (CDI) metrics for the REU students to improve upon an existing platform design.

The VA technique aids designers in finding the best way for addressing the customer's needs. It checks if the function requirements (voice of the customer) are correctly specified for each component. If the design does not respect these requirements by over or under sizing the design then improvements can be made to better satisfy these requirements. The designers would also try to reduce the number of components during this stage of platform improvement.

The Design Structure Matrix tool is based on the physical relationship between components[26] used at the beginning of the design development to specify feasible modules. The rationale behind the DSM is that groups of components physically related to each other assumes that a modular construction is better than having separate components. As seen in Table 1, the DSM is a matrix where components are represented on the top and on the side, and where each physical relationship is identified by the number 1. The limitations of the classic DSM are that only physical limitations are integrated and it usually does not integrate the environment. Thus, another type of interaction was added: the flow interaction to create the DSM_{flow}. This new addition integrates all types of flow interactions and also takes into account the environment. This extension is necessary to have a global view of the system and the interaction between components. For example, if there is a flow of fluid (e.g. water) between two components, it is useful to keep the components close to each other. Also, the whole system is studied with the "users", the environment, and the "fluids" (water in this example).

Table 1. Example of a Design Structure Matrix *flow*

\	Refrigerator Door	Freezer Door	Dispenser	Top Hinge	Bottom Hinge	Ref. Hinge Cap	Freezer Hinge Cap	User	Water
Refrigerator Door				1	1			1	f
Freezer Door			1	1	1				f
Dispenser		1						f	f
Top Hinge	1	1				1	1		f
Bottom Hinge	1	1							
Refrigerator Hinge Cap				1					
Freezer Hinge Cap				1					
User	1		f						
Water	f	f	f	f					

The CDI[27] is based on the allowed diversity and the non-allowed diversity in a product family, where some functions are common and some are unique to satisfy specific needs. This new index considers that if the functions are supposed to be same, then the components must be the same; if the functions are supposed to be different, then the components must be different; and, if the function is a variant from the rest, then the components must be variant (similar component adapted for each product) in the same proportion. The advantage of this index is that it considers the commonality and the diversity combined in the same index by increasing the value when commonality and allowed diversity are respected. Another benefit of this index is that it considers both (1) the product family aspect by examining the family for a good commonality/diversity score across the products; and, also studies (2) the function aspect to assess if each function has a good commonality/diversity score with the family. These aspects help designers identify which component of which function of which product can be enhanced. The REU program described in the next section covers how the students used these metrics along with product dissections and the UMR repository to learn about product platforms and the efforts for improving the management of information within product platform design.

3. Implementation and Structure of the REU program

In the Summer of 2005 five students were hired from the four institutions, two from UMR and one each from the remaining universities. The students spent four weeks working at Bucknell and then another four weeks working at Virginia Tech with a weeklong break during the July 4th weekend in between. The break gave the students a chance to visit family and friends or return home to their respective schools before going to Virginia Tech. At the end of the REU program, the faculty working under the ITR grant all met through a conference call at Virginia Tech to listen to the REU students give a group presentation describing their accomplishments during the program.

Housing at both Bucknell and Virginia Tech were provided through summer housing programs that were being run by the respective schools. Some of the REU funds were allocated to cover travel expenses for the students to move into the hosting institutions. As for their work during this eight-week program the students each received $4000. In the Summer of 2004 the REU program was held in PSU and UMR with similar arrangements.

During the duration of the program, students spent the majority of their time dissecting and analyzing products from different product families. In the eight weeks the students managed to dissect and capture necessary information on 21 power tools from four product families, 18 Kodak disposable cameras, three Stapler® One Touch Staplers, two Whirlpool® refrigerators, and five Mr. Coffee® coffeemakers. Working with such a diverse selection of products allowed the students to see the applicability of platforms and how they were used by the different companies.

The Bucknell and Virginia Tech portions of the program were structured differently. The Bucknell portion of the program had the students dissecting a multitude of products to help them understand the concept of platforms and information management for such design strategies. Product information was also extracted from the dissections to support several research focuses in the ongoing collaborative research. In Virginia Tech the students worked closely with the design repository at UMR. Supplemental information such as assembly and function structure diagrams required for the repository were made for the products dissected at Bucknell. As more products were dissected at Virginia Tech the students were also subjected to case study projects, designed for future educational use by the institution. Figure 2 has pictures of the REU students during a product dissection at Virginia Tech.

Figure 2. REU students at Virginia Tech

Bucknell:

Step 1 – Product Dissection to the lowest level possible: To familiarize the REU students with the product platform research they were presented with several product families and instructed to dissect the products down to the smallest level possible, the component level. Products such as the refrigerator, which contains complex components, were dissected to the module level. Product dissections gave the students a hands-on learning experience on how companies incorporate platforms in their product families. This step also gave the students a chance to become the product engineers. They actively thought of how they could design the product better and concurrently learned about the underlying factors and processes that go into developing a product. Figure 3 is an example of how the REU students compared dissected products with its other members of the family.

Figure 3. Three Stapler® One-Touch Staplers dissected to the component level.

Step 2 – Capture information and apply the CDI: Once the products were dissected, information necessary for fulfilling the needs of the UMR repository as well as the novel design metrics were recorded. This entails capturing the product component's functions, dimensions, materials, connections, flows, and cost. The CDI, being developed by Alizon, was applied to the dissected products to garner a score which reflects the efficiency of product platform use within the family. The products used in the research produced high CDI scores (scores range between 0 and 1) and were expected to since they were designed with the platform approach. All of the product families displayed a high level of commonality while also retaining their differentiating features. The CDI of a Kodak disposable camera can be seen in Figure 4.

	Diversity for the Function	0%	20%	20%
Display Information	Zoom	1	6	1
	Plus digital	2	2	2
	HD	1	1	1
	HQ	1	1	1
	W&S	2	3	-
	Power flash	3	1	1
	Advantix	4	5	4
	B&W	2	2	2
	Fun saver	3	4	3
	Outdoor	5	1	-
Score	0.62	0.56	0.66	0.66

Figure 4. CDI applied to the Kodak one-time-use disposable camera family.

Step 3 – Applying the REUSE method: The Reuse Existing Unit for Shape and Efficiency method, also being developed by Alizon[28], was applied to the product's components to validate the method as an appropriate tool for a database query and also as a management tool. Based on a similarity study, efficiency assessment, and configuration stage, the REUSE method was applied by the REU students to properly extract desired existing components belonging in a database for a new product. As a management tool, the REUSE method: (1) observes what components are well known and reusable, (2) discovers which components are mostly unknown and require more design resources, (3) knows what work has to be done on preliminary steps of the project, and (4) reduces cost and project time while making design time more predictable.

Step 4 – Product improvements and recommendations: Based on the CDI, REUSE and VA, the students made recommendations for product/component redesign in order to increase commonality within the family. Recommendations were made along the lines of reusing common parts across the family, redesigning dissimilar components that share the same functions, and utilizing more modular/scalable components. CAD models were used to visualize how some of the components could be redesigned to become more interchangeable within the product line. Figure 5 shows some of the components redesigned in ProEngineer based on the suggested improvements and recommendations.

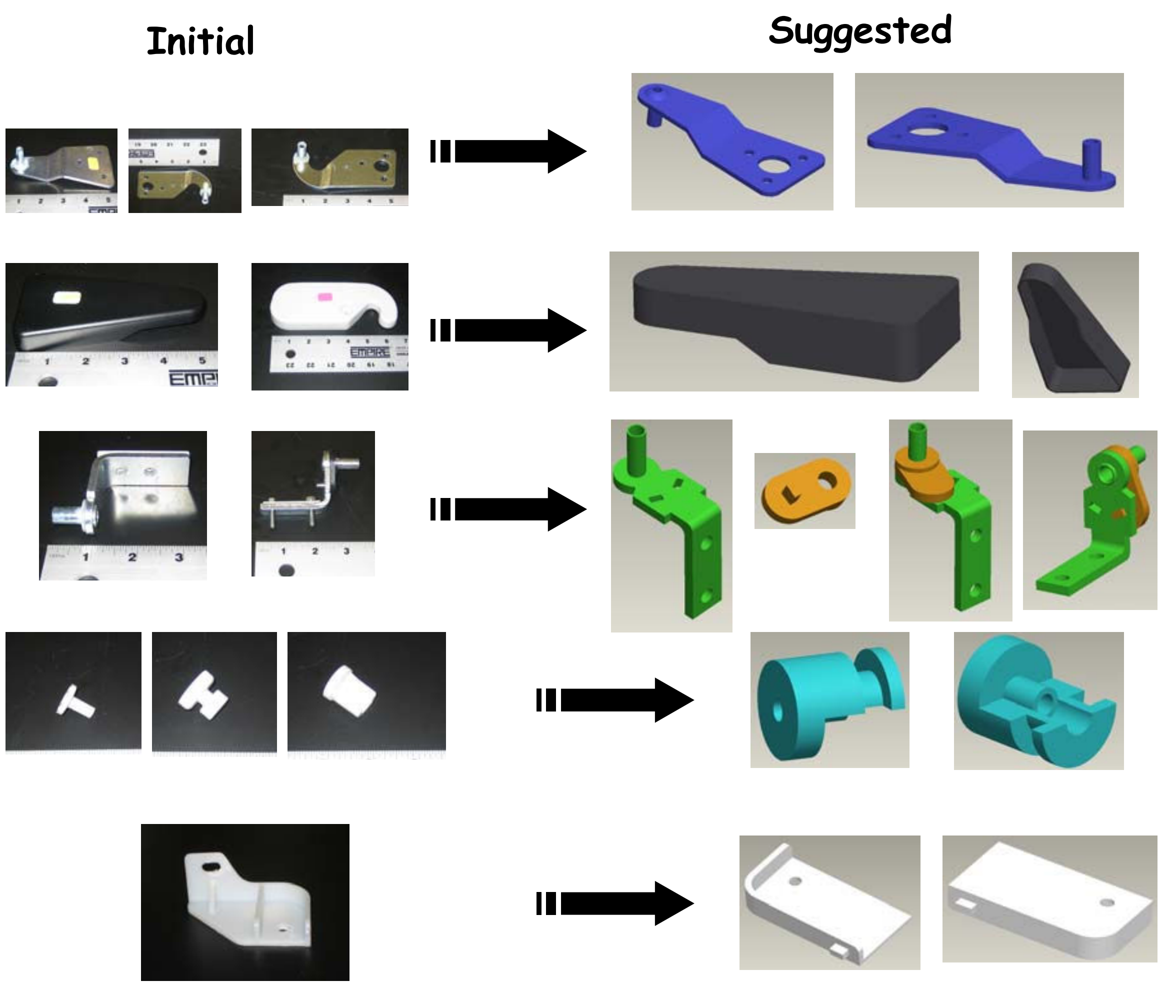

Figure 5. Redesigned components from the Whirlpool refrigerators using ProEngineer.

Virginia Tech:

Step 1 – Create assembly and functional diagrams: The students revisited the products dissected at Bucknell and created assembly and functional diagrams to be incorporated into the UMR repository. The assembly diagram provides a tool for the design engineers using the repository to visualize how the components listed in the repository interact with other components of the product. The assembly diagram is also a great tool for product innovation and redesign since it serves as the blueprints for existing products. The assembly diagram for a Whirlpool refrigerator is shown in Figure 6. Each assembly diagram includes a key to indicate how connections are made. The students also constructed function structure models which were used to describe, in a form independent manner, how the product functions. The students used the functional basis that is being developed by Stone and his colleagues[29, 30]. The input, output, material and energy flows, and functions for a Kodak disposable camera are shown in Figure 7. The assembly and function structure models were created using the software package Concept Draw V.

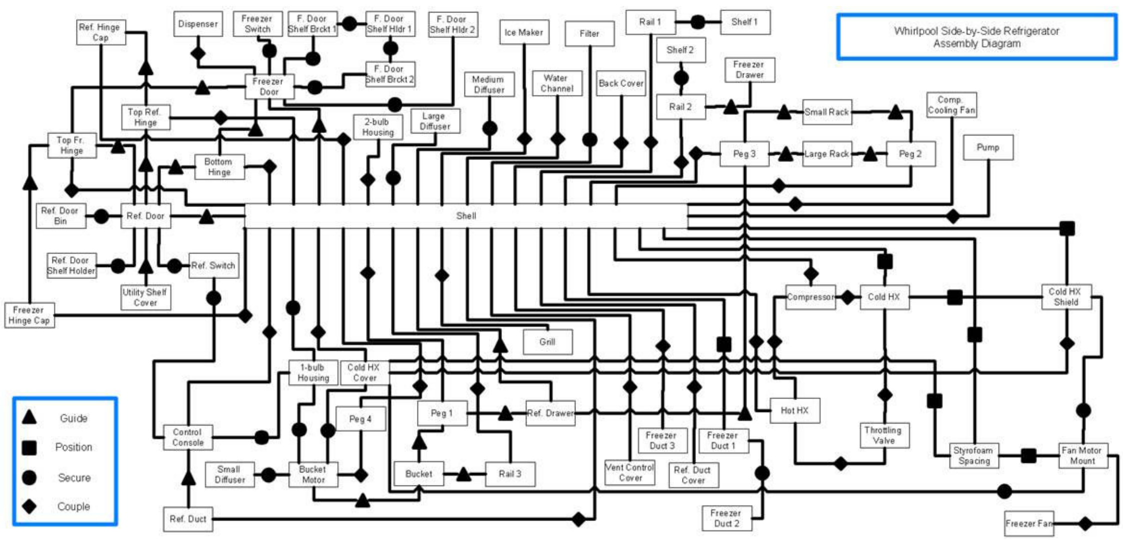

Figure 6. Assembly model of a side-by-side Whirlpool refrigerator

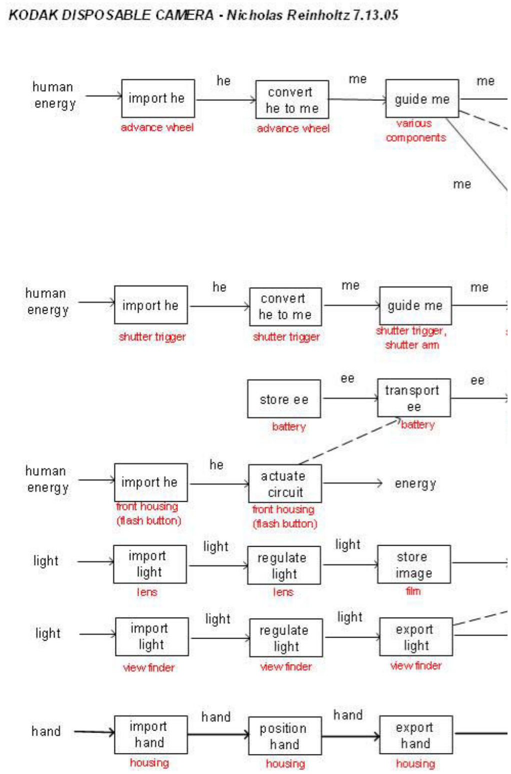

Figure 7. Function structure model of a Kodak disposable camera.

Step 2 – Populate the UMR repository: The students repeated the dissection procedure performed at Bucknell to a set of coffeemakers by Mr. Coffee. For this instance the information collected during this period was tailored more towards the repository and was introduced to the database through the software, FileMaker Pro. Assembly and function structure models were also created for these products. Stone and his graduate students later obtained the data provided by the REU students to populate the web-based repository. Based on suggestions made by REU students from the previous year data entry into the repository was improved. After working with the repository software this year, the students made some more suggestions for further improvements:

- FileMaker had some issues with the way data was entered. Some things, such as the tabbing order can really make a difference in the speed and efficiency of data entry
- The repository was unresponsive at times
- The structure of the repository should be more hierarchical and less linear
- Pull-down menus should be more context specific

Step 3 – Product platform case studies: The REU students completed the case studies that are available on http://www.enge.vt.edu/terpenny/Smart/Case-study-website/Index.htm. This website provides a detailed look into the emerging philosophy that is product platforming. It provides thorough lessons on the phases of product platform design from the customer needs end to the platform development phase. The goal of this part in the REU program was to test the workability of the case studies for future educational use. The REU students had to use their knowledge from their experience during the program to design new products based on an existing product family. The case studies involved creating derivative products from horizontal and vertical leveraging strategies and also creating new product platforms based on market research. Overall, the case studies helped the REU students further increase their knowledge about product platforming and product design. A screenshot of the website can be seen in Figure 8.

Figure 8. Product platform learning tools available on the web.

4. Evaluation and Student Feedback

One of the mission statements of this REU program was to increase the students' awareness in graduate schooling as well as research and work in the field of product design. The responses from the students conclude that this REU experience have successfully achieved its goals. "This program raised my awareness about graduate school opportunities. I became extremely enthused about graduate school and even purchased two GRE study books during the summer." Also, "It was very interesting to be able to apply the same idea of product platforms to a wide variety of products." In addition, this program exposes the realm of design in higher detail that many institutions do not get to explore in their curriculums. "I have always been interested in design. This program helped me understand which aspects of design interested me and which ones didn't."

The working environment of this program was designed to simulate a graduate school environment with much emphasis on research. "The REU program reinforced my interest in grad school by providing an experience similar to that of grad school. In addition, we had to use and improve our time management skills to complete the work by the required deadlines. Through the REU experience, I was able to determine that I would indeed succeed and enjoy graduate studies." When asked about the overall REU experience, "My favorite part of the REU experience was working with students and professors from other universities. It was a great opportunity to perform research and meet a bunch of great people with similar interests." Outside of the program, the students enjoyed many facilities and attractions that the campus and nearby towns had to offer. "We went to many fun events outside of work and quickly became good friends."

Along with the rest of the REU students, I also had a wonderful experience with this program. During this Summer I was able to learn much about design and Product Platform Planning. Dissecting everyday products not only taught me how the products worked but helped me understand why the products were designed a certain way as well. As a result, I now have a much higher appreciation for the way things are designed. Working alongside other researchers granted me the chance to learn about product platforming with a much larger scope. It was also nice to work with the other students in this program who share much of the same interests as I do. Furthermore, this program has also allowed me to embark on my own research with one of the program's professors to do work in the field of information management and Product Platform Planning.

5. Closing Remarks and Future Work

In this paper we have described an undergraduate research/learning experience where students from 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 a total of 49 products from eight different product families. This information was then used to populate the design repository at UMR and support other research in the collaborative effort. 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 seeking further education in graduate school and 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. The results of their efforts are supporting many avenues of our current research: commonality assessment and platform redesign[31], product family information capture[32], product family ontology development[33], and online learning for product platforms[34]. 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.

The students have also given many suggestions to improve future offerings of this REU program. Students felt there was a "disconnect between the goals of the two universities" nevertheless, they understood that this was necessary for exploring the many avenues of this collaborative research. It was also difficult for the students to reuse information extracted from the Bucknell portion of the research to do the work at Virginia Tech due to a lack of formalized data capture methods in some areas. An example of this is the absence of a naming convention for product's components. Also at Virginia Tech, the students felt that it was difficult to work without the dissected products readily available; the students had to rely on captured images instead. We plan to implement these and the aforementioned changes in future offerings of this multi-university REU program.

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