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Role of Artifacts in Creating a Self-Renewing Design and Manufacturing Community of Practice

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Abstract

Locally produced hardware with site-specific shop equipment serves as a powerful context for generating customized instructional materials to undergird design and manufacturing education. Enlisting students as authors of these instructional materials further provides an opportunity to enhance their project learning. Formatting these materials on wiki pages, in turn, provides a convenient method for efficiently retaining important design as well as manufacturing knowledge for subsequent use by a larger audience. By linking this digital information with engineering artifacts and manufacturing tools via QR codes, potential users can have just-in-time, point-of-use access (via their cell phones) to design features and design realization details. These are the ingredients of a Web 2.0 approach for knowledge management that has been integrated in our lean manufacturing elective as well as our capstone design sequence. Results from recent e-resource prototyping are inventoried as are ideas for continuing development.

Introduction

Curiosity, critical thinking, and creativity are attributes needed in modern industry by machine designers and product developers[1]. As a complement to formal instruction, these skills can be nurtured in informal learning situations through timely exploration of a diverse library of artifacts along with the manufacturing tools used to produce these artifacts. Furthermore, students can be valuable allies in creating and sustaining locally produced resources for such a library, leaving a legacy of design products and fabrication techniques for the next generation of students. Previous work by the authors described design specifications, development methods, and assessment tools for student-authored machine shop videos[2]. In the intervening years, the inventory of locally generated design products, design process documents, machine shop quick references, software tutorials, engineering drawing packages, part and component renders, and assembly animations has continued to accumulate. At the same time, mobile technology has matured and become widespread. Most students now own handheld devices that can capture, scan, and display images as well as access the internet at high speed. Students are also adept at using social media to create content and participate in virtual communities. The stage is now set for deploying a web-based system for converting a multitude of design artifacts and associated learning objects into interactive, museum-like exhibits that can mediate situated learning in the design suite, in the machine shop, and amidst a gallery of capstone project posters. This paper reports on initial efforts to implement such a system in support of just-in-time project learning. The system is uniquely designed to operate within our design environment. It has evolved over the last two decades to reflect shared beliefs about design pedagogy and product realization.

Educational Setting

Our inter-disciplinary capstone design program has been a catalyst for local design infrastructure development and has evolved through a continuous stream of projects from regional industry, equipment donations from alumni and industry supporters, part-time graduate student support from the National Institute for Advanced Transportation Technology, part-time graduate student support from the Mechanical Engineering department, and two NSF educational research grants. Results from over 25 capstone design team projects are shared each year with the public, alumni, and industry partners at a signature university event known as the Design Expo. The university commitment to this program has resulted in construction of a 6000 ft^2 design suite that includes a CNC-equipped machine shop, metrology lab, project assembly area, advanced CAD laboratory, 3D printer, conference/study area, design review studio, and nearby graduate student offices. These physical and virtual prototyping spaces are on display for all who visit the design suite through an extensive set of windows in the building entry way. The overall learning environment is engaging for upperclassmen as well as enticing to prospective freshmen, transfer students, engineering underclassmen, and project sponsors.

To make the capstone program self-sustaining, a system of knowledge management has evolved to retain both explicit and implicit knowledge. Explicit knowledge is captured and transferred through a website that contains over 400 videos, quick references, and project vignettes. Implicit knowledge is transferred through the Idaho Engineering Works (IEW), where a group of graduate students is given specialized training in hardware, software, manufacturing, and leadership with the expectation that they will mentor undergraduate students in their design and manufacturing work across the curriculum[3]. In this manner, explicit knowledge contained on the website has been mediated for just-in-time use. Because of its attention to these elements our capstone program was recognized in 2012 by the National Academy of Engineering as an exemplar for infusing real world experiences into engineering education[4].

Our design program is continuously being rediscovered, tested, revised, and adapted. To date, this has been a 21 year journey. This self-renewing process is a collaborative consensus-building activity that easily integrates new faculty and students, and also allows veteran faculty to step out for sabbaticals and other interests, and then seamlessly return. Six core values underlie the implementation of our program:

Professional Integrity: day-to-day and long-term actions, aligned with professional codes of ethics in ways that are relevant and meaningful, responding to the needs of clients and society at large.

Growth Oriented: awareness of current knowledge, skills, and learning styles, informing self, peer, and mentor actions that elevate performance expectations while providing needed support for measurable change in professional behaviors and attitudes.

Technically Competent: enlightened use of engineering principles, early prototyping, modeling, experimentation, application of appropriate software tools, selection of state-of-the-art components, problem formulation/decomposition, and specification of manufacturing methods.

Collaborative: respectful, supportive, empowered community of practitioners promoting mutual understanding of diverse motivations and complementary skills while working towards a shared vision.

Resource Rich: inspiring work environment providing ready access to prior work products, catalogs, instructional videos, software tutorials, and expert consultation as well as multiple opportunities to learn and use state-of-the art tools for computation and manufacturing.

Value Added: significant return on investment by developing compelling project goals that respond to stakeholder needs, innovating, measuring progress through systematic collection and analysis of data, assuming responsibilities needed for efficient and effective results, and compiling documentation that allows others to adopt solutions.

Impact on Program Outcomes

Outcomes of our design and manufacturing program fall into four general areas: student learning, program operation, infrastructure development, and community development. Central to each of these outcomes are deep student, faculty, and staff engagement as well as enduring attention to knowledge management.

Student learning outcomes include: (a) deep immersion in and reflection on self-directed project learning, (b) early prototyping that accelerates and improves the quality of final designs, (c) formal communication (oral and written) that allows clients to easily integrate design project results, and (d) cadre of graduate student mentors with exceptional technical leadership skills.

Program operation outcomes include: (a) annual planning, oversight, and assessment that produces yearly improvements, (b) project results that delight all stakeholders, leading to follow-on projects in subsequent years, and (c) minimal cost to produce results, leading to increased financial resources for infrastructure.

Infrastructure development outcomes include: (a) locally produced, web-based design tools, rubrics, and quick references for just-in-time professional development, (b) innovative learning spaces for virtual and physical prototyping, and (c) diversity of well-maintained CAD, manufacturing, and metrology hardware/software that supports the creation of metal, plastic, and printed circuit board parts.

Community development outcomes include: (a) vertical integration of design, engineering science, lab, and graduate courses for better product/process results, (b) contributions to regional economic development recognized by our State Board of Education, the Northern Idaho Manufacturers Association (NIMA), and TechHelp which is Idaho’s statewide Manufacturing Assistance Program, (c) alliances with other units on- and off-campus that lead to new and exciting project opportunities, and (d) recent recognition by the National Academy of Engineering as an exemplar of hands-on real-world engineering learning.

It is within this context that we have begun to experiment with moving locally produced design and manufacturing guides from a Web 1.0 format into the world of Web 2.0. Web 2.0 refers to web sites that are more than just static pages maintained by a single webmaster. The term was coined about ten years ago and while it doesn’t prescribe specific web standards it is commonly used to describe websites that use social media tools to enable users to create content and become more active members in virtual communities. Our vision is to stimulate more self-directed, point-of-use access by connecting design artifacts and design tools with internet-delivered, interactive displays. For now, the medium for this connection is QR codes, but we hope to replace this method with image recognition utilities in the near future.

Mindworks Components

Central to our design program is a learning environment known as Mindworks. This is infused throughout the design suite and is aligned with our core values. It was created to (1) promote a culture of professional decision making in engineering design, (2) house a variety of physical and virtual resources that support project learning, and (3) serve as the delivery system for a variety of engineering graphics, manufacturing, and simulation courses as well as the capstone design experience. Physically, there are artifacts including mechanical models, wall decorations, design guides, vendor catalogs, computer projection equipment, and abundant white boards. Virtually, there are just-in-time resources for project learning in solid modeling, computer aided design, design for manufacturing, and formulating machining plans[5]. Most quick references are less than two pages; most videos are less than 6 minutes; and most tutorials can be completed within 15 minutes. We have observed that this modularity promotes more frequent use and re-use inside as well as outside formal class settings. Culturally, Mindworks supports a thriving community of undergraduate engineering students, graduate student leaders in the Idaho Engineering Works, and professional staff. It is a preferred learning and problem solving space in which these stakeholders choose to spend many hours each week.

Figure 1 depicts a physical model used for machine design learning. Many of these have been produced through kaizen projects in our lean manufacturing technical elective. The artifact that is shown in Figure 1 illustrates the importance of dimensions and tolerances when specifying running clearances. The artifact has different clearances for pins and bolted connections, and shows how pins can be used to align parts instead of fasteners doing the alignment. The artifact is alluring with a story that should be told at the time and place that the block is being examined.

Figure 1. Manipulative Model for Machine Design Learning

Table 1 lists student-authored machine shop guides, also produced through kaizen projects in our lean manufacturing class. Some of these have been framed or laminated, adding to the visual work environment within our shop. Many others are one- and two-page Powerpoint and Word documents that need to be downloaded and are best viewed on a personal computer.

Table 1. Student-Authored Shop Guides

Manual Operations	CNC Operations	Outsourced Operations
Mill Gear Change	HAAS Mill Setup	Anodizing
Mill Head Tramming	HAAS Mill Panel Controls	Applying Images and Decals
Mill Z Axis Feed	HAAS Mill 4th Axis	Electric Discharge Machining
Lathe Standard Practices	HAAS Mill Machining	Heat Treatment
Lathe Gear Change	HAAS Mill Machining	Laser Cutting
Lathe Dial Indicator	HAAS Mill Machine Plan	Plasma Cutting
Lathe Tools	CNC Lathe General Info	Water Jetting
Horizontal Band Saw	CNC Lathe Canned Cycles	
Welding General Information	CNC Lathe Panel Controls	
Welding MIG	CNC Lathe Machine Plan	
Welding TIG	Bridgeport Mill	
Hydraulic Press	MasterCAM Mill	
Belt Sander	MasterCAM Lathe	

Table 2 lists work products by multiple generations of design teams in our introductory solid modeling course, kept as an archive of exemplary past projects alongside on-line solid modeling learning activities. This is a mid-program virtual dissection and re-assembly experience in which project teams are given hand-drafted legacy drawings, often from the community of small engine builders, and expected to create a fully-functional assembly model as well as a comprehensive engineering drawing package[6].

Table 2. Examples of Team Project Outcomes in Solid Modeling (with SolidWorks)

Project	Year
Model A Transmission	Fall 2009
Model A Engine	Spring 2010
Wright Brothers Engine	Fall 2010
Marine Petrol Engine	Spring 2011
Barr and Stroud Vertical Cylinder Engine	Fall 2011
Marine Steam Engine	Spring 2012
V8 Scorpion Engine	Fall 2012
Wright J5 Radial Airplane Engine	Spring 2013

The Mindworks website is linked to inter-disciplinary capstone design webpage which contains a portal with details about over 200 capstone projects undertaken since 1996[5,7]. Table 3 gives examples of capstone project webpages taken from the last six years. Separate pages were requested for problem definition, concept development, finished product visualization, design evaluation, team profile, and design documents. While the finished products are attractive and informative, they were authored by a single team member, often at the end of the design process, and they contained elements which could not be easily retrieved or reused by future capstone teams. One of our motivations for pursuing next generation web technology is to increase institutional memory and reflection on valuable lessons learned in previous capstone projects.

Table 3. Examples of Capstone Project Webpages

Project	Website
Pumpkin Cannon	http://seniordesign.engr.uidaho.edu/2012-2013/pumpkinshooters/index.html
Transformer Tap Changer	http://seniordesign.engr.uidaho.edu/2011-2012/phaseshiftingtransformer/pttschome.htm
Timber Grading Apparatus	http://seniordesign.engr.uidaho.edu/2010-2011/flexgrade/index.html
Solar Heated Pool	http://seniordesign.engr.uidaho.edu/2009-2010/iheat/index.html
Ballistic Test Fixture	http://seniordesign.engr.uidaho.edu/2008_2009/pyrovandaleers/index.htm
Hot Cell Manipulation Equipment	http://seniordesign.engr.uidaho.edu/2007_2008/hotrod/

The Mindworks website is also the delivery platform for the introductory solid modeling course, the senior design sequence, the lean manufacturing course, two different advanced CAD courses, the engineering thermodynamics course, and the combustion engines course. All have a similar three-column format with materials organized into pre-class activities, in-class activities, and homework assignments. Formal coursework includes strategic use of supporting machine design, solid modeling, and machine shop references. This is done intentionally to initiate bridge-building between formal and informal learning in engineering work.

We believe that Web 2.0 technologies and authoring techniques can make this transformation even more robust. As a first step, we began subscribing to a wiki service and have begun training our students in the use of wiki templates. We also began researching best practices in the creation of ambient displays for learning. We discovered a fascinating literature on industrial archeology (cataloging of man-made artifacts to understand their design intent and use) and museology (display of artifacts to engender audience interest and inquiry) that we have begun adapting for design and manufacturing education[8,9,10,11,12].

Web 2.0 Design Principles

In our implementation of the next generation Mindworks e-resource, we have adopted a variety of best practices from social networking sites, blogs, and video sharing sites. Entry points should be authentic (within design and shop spaces, not just in computer laboratories), conspicuous (attracting attention at the point of use), and engaging (stimulating user interest through compelling narratives with strong visual and auditory elements)[10]. Information and interactivity invoked by displays should follow best practices for digital learning objects[11]. They should be self-contained and scoped to answer salient questions associated with a physical artifact within 2-5 minutes. They should be structured for naturalistic use with a handheld display unit, preferably by scrolling down rather than menu navigation. They should have a consistent organization for meaningful grouping into larger collections for formal learning (traditional courses) as well as informal learning (at strategic moments in engineering project work). They should also create new knowledge by juxtaposing physical and virtual elements and be tagged with appropriate metadata in order to facilitate searching[11]. Ideally, the user experience should be perceived as enjoyable and timely, even after repeated use[8]. The resulting experience should provide feedback that grows situational awareness and reinforces desired professional behaviors. The system should serve as a self-directed personal learning environment that provides a productive level of challenge in response to critical thinking questions about design and manufacturing[9].

Machine Shop Case Study

The first implementation of wiki sites was in a subset of kaizen projects undertaken in the 2013 lean manufacturing elective. Students prioritized kaizen assignments aligned with personal interests. Pairs for each project were then formed based on these preferences. Pairs were first asked to interview the shop manager as well as graduate student mentors familiar with the kaizen topic. This was followed by an analysis of existing peer-produced resources as well as other resources associated with each topic. Next, pairs created a storyboard that defined the current state/need as well as a credible future state/goal that could be achieved before the end of the course. Pairs then participated in a wiki authoring workshop where they used common procedures for assembling information in a hierarchical format and placing images side by side with text in easy to read and easy to manage table structures. At the conclusion of the workshop, students a created QR code that pointed to the wiki page they had just authored.

Outcomes of kaizen project work were shared in end-of-course ambient displays located around the machine shop. Stickers with QR codes were placed on relevant shop equipment and point-of-use posters. Figure 2 illustrates use of a point-of-use cleaning poster for a manual mill. A laminated sheet with these instructions is permanently kept out on the mill bed. The QR code links to a wikipage that provides more information why cleaning is important, proper cleaning procedures, things to avoid, and commonly missed messes. We encourage the reader to experiment with accessing this wikipage from the QR code in Figure 2.

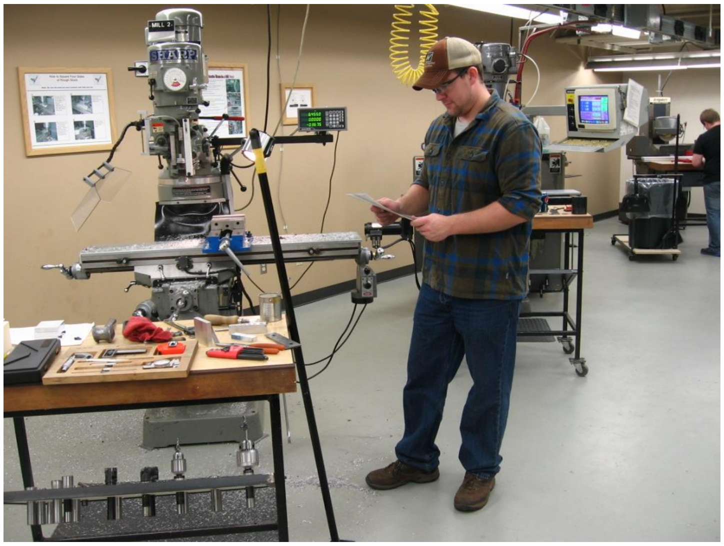

Figure 2. Shop Use of Mill Cleaning Reference Card w/QR Code.

A listing of shop wikipages created to date is given in Table 4. They remain in use and have been adopted in shop orientation sessions facilitated by graduate student mentors.

Table 4. Student-Authored Wiki Sites for Machine Shop Learning

Resource	Wiki Site
Logan Lathe Operation	http://mindworks.shoutwiki.com/wiki/Manual_lathe_(Logan)
Mill Cutters	http://mindworks.shoutwiki.com/wiki/Cutter_Types_(Mill)
Cleaning Shop Machines	http://mindworks.shoutwiki.com/wiki/Cleaning_Machines
Tramming a Mill Head	http://mindworks.shoutwiki.com/wiki/Tramming_Mill_Head
Squaring Rough Stock	http://mindworks.shoutwiki.com/wiki/Squaring_Rough_Stock
3D Printer Parts	http://mindworks.shoutwiki.com/wiki/3D_Printing
Using a Micrometer	http://mindworks.shoutwiki.com/wiki/Micrometer_Measurements
Haas Mill Tool Mounting	http://mindworks.shoutwiki.com/wiki/Mounting_Tools_(HAAS_Mill)

Capstone Design Case Study

The 2013 summer/fall offering of the senior design sequence included a course requirement to create project wiki pages as an alternative to project web pages. The wiki workshop used in the lean manufacturing course was upgraded with more on-line support. This included a general information page, a developer's bulletin, and an index of all pages created to date. A special summary box was designed to contain project metadata that includes a picture of the finished prototype, identification of sponsors, team name, project duration, faculty advisors, and graduate student mentor. Templates were also created for checklist tables, advantages/disadvantages tables, and itemized/step by step tables. All capstone students participated in the wiki workshop, they explored different elements in the developer's bulletin, and they experimented with the templates. Numerous opportunities were provided for wiki consulting, but peer-to-peer consulting within and between capstone teams kept this a minimum. Wiki pages were assessed mid-project and end-of-project by lead instructors. Several of the teams voluntarily used QR codes on their final posters as a means of connecting their display of end-of-project hardware with the story behind their design. Members of the 20+ teams in the 2013-14 fall/spring offering of capstone design have readily re-used codes and organizational ideas from the materials in Table 5, further simplifying the authoring process for this generation of students.

Table 5. Examples of Student-Authored Capstone Wiki Pages

Project	Wiki Site
Marching Band Drum Set	http://mindworks.shoutwiki.com/wiki/Band-Beesten_rolling_drum_set
Snowmobile Rear Drive	http://mindworks.shoutwiki.com/wiki/CSC_rear_drive
Thermocycling Apparatus	http://mindworks.shoutwiki.com/wiki/Hot_Start_thermo_cycler
Design Suite Signature Clock	http://mindworks.shoutwiki.com/wiki/Signature_Clock
Soil Temperature Probe	http://mindworks.shoutwiki.com/wiki/Wildfire_temperature_probe

Conclusions

Locally produced hardware and site-specific fabrication equipment has a powerful story to tell in design and manufacturing education. By combining wiki pages, QR codes, and cell phone technology, this story can be told at the right time and place within an educational environment. Learning this story, assembling images to enhance this story, and retelling the story for peers is a student activity that we have successfully integrated in our lean manufacturing technical elective and capstone design sequence. Success in this activity has not been instantaneous. It is a product of a student-centered and learning-centered educational philosophy that has evolved over two decades. Authorship is at once everywhere, nowhere, and ever-changing. Our Mindworks resources along with the larger learning environment of which they are a part, result from a collaborative, and never ending, endeavor between undergraduate students, graduate students, faculty, and professional staff.

With these instructional opportunities and cautions in mind, the Mindworks Website along with the Mindworks Shoutwiki sites featured in this paper represent a sensible framework for others to organize their own digital libraries/artifacts. Steps that we believe are essential in creating and sustaining a similar resource collection are:

- Form a team of faculty engaged in related educational experiences (CAD, lean manufacturing, machine design, and capstone design in our case) who have congruent educational philosophy and who are willing to provide stewardship of the resource collection over time.
- Identify specific resource topics that are both developmentally appropriate and can be satisfactorily completed with reasonable effort by typical students in the program.
- Compose meaningful specifications for content organization that ensure sets of resources have a familiar look and feel.
- Engage cognizant faculty, staff, and graduate students in consultation with student authors about key information sources and best practices surrounding their authoring assignments.

- Have multiple stakeholders (faculty, professional staff, graduate students, undergraduate peers, and IT coordinators) assess resources for accuracy and usability before finalization.
- Purposefully re-use resources at different points in the educational program, illustrating that knowledge and best practices encapsulated in the resources transcend individual courses.

We are now beginning to explore ways to package critical thinking questions with different artifact-centered, digital resources in a manner that can enrich pre-class assignments, hands-on workshops, and design team meetings. We look forward to leveraging augmented reality products just coming onto the market in this quest. We also hope to use the work reported here as a proof-of-concept for campus IT decision-makers, convincing them of the need for a campus-based wiki server that is under local control, has more administrative options for opening/closing editing groups, communicates our campus brand, and is without any embedded advertising. Despite these changes we are committed to keeping contents of the wiki publicly available as this has proven to be a valuable tool for networking in the design for manufacturing community.

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