INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

DESIGN KNOWLEDGE COACHING – A CONCEPTUAL FRAMEWORK TO GUIDE PRACTISE AND RESEARCH

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ABSTRACT
Research and development of digital libraries has been largely focused on technological development in the past. Despite the huge efforts that have been made to develop these systems, it has been shown that users often do not accept them. Some recent research on digital libraries has therefore focused on the user and on identifying the factors that lead to increased user acceptance of this technology. However these efforts tend to focus on static scenarios, in which the system is optimized for a specific interaction scenario. Innovation focused design processes are highly dynamic, and the value of a specific piece of information can change rapidly over the course of a project. Digital library systems have not accounted for these dynamic changes. Our experience suggests that coaches, who can adapt with context, can connect users and knowledge successfully. However we lack a framework to guide the studying and systematic improvement of this interaction of the coach. Building on results from two exploratory studies on the usage of digital libraries in the context of an engineering design class, we propose a conceptual knowledge-coaching framework. The framework gives suggestions to improve the interaction of a coach as mediator and moderator of the information flow between a user and an information source.

Keywords: Digital libraries, coaching, ambiguous design problems, video, re-use, tacit knowledge, explicit knowledge, autonomous learning

1 INTRODUCTION

1.1 Motivation: Facilitating information transfer
Research and development of digital libraries has been largely focused on technological development in the past. Despite the huge efforts that have been made to develop these systems, it has been shown that users often do not accept them [1]. Some recent research on digital libraries has therefore focused on the user and on identifying the factors that lead to increased user acceptance of this technology. One successful approach in that direction has been the application of the Technology Acceptance Model (TAM) [2] to research on digital libraries [3]. The Technology Acceptance Model places perceived usefulness and perceived ease-of-use as the key determinants for the acceptance of information technology. However the success of this approach relies on a static scenario. The predictions for future usage are made based on a scenario, which resembles the future usage scenario closely. A design scenario is highly dynamic. Information needs of designers cannot be predicted [4]. The value of one piece of information changes rapidly over the course of a design process, and with it the perceived usefulness and ease of use of a digital library system. For example a video of a past project presentation can be entirely useless at the beginning of a project because of different project topics, however at the end of a project, the very same video can become extremely valuable as it provides an example of a successful presentation style. The value of information depends highly on context. In design, context changes rapidly.
Digital library systems have not accounted for these dynamics. In this paper we argue for placing a human in the loop - a coach that can adapt with context and connect users and information successfully to facilitate the creation of knowledge. Knowledge is used here as information that has been given meaning. Meaning can be given for example through, context, relevance, and interpersonal factors.

Interestingly, "coaches" already exist in many organizations. They are people who powerfully connect others with new information. They affect how valuable a piece of information is to us and how easy we can access it. Such a knowledge coach can be someone who points out a relevant example of a past project for us, or someone who introduces us to another person, and therefore makes that information exchange so much easier. Eris has shown the important role that expert coaches play in facilitating the successful adoption of new information technologies by design teams [5]. He identified the three key learning mechanisms within design activity through which knowledge acquisition takes place.

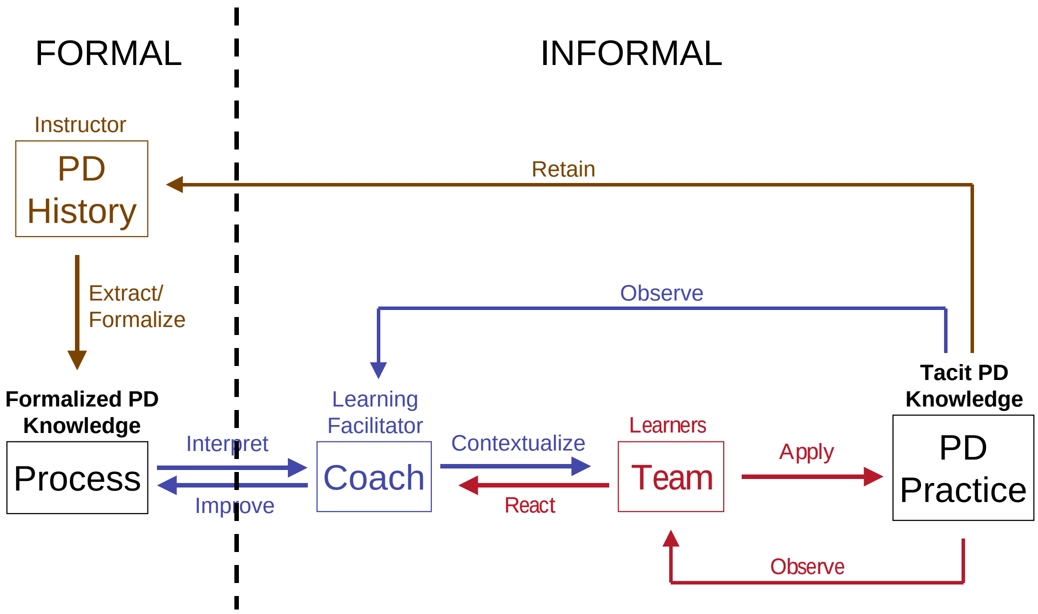

Figure 1. A grounded product development knowledge acquisition model derived from empirical findings. [5]

The Knowledge-Acquisition-Model builds the basis for the research described here. In the context of information transfer, it powerfully shifts the focus on coaching. Many powerful examples exist, in which humans play an important role in bridging the gap between users and information. However no frameworks exist that guide research and praxis of this interaction. In this paper we propose a way of understanding the underlying mechanisms of what is happening in this interaction. Based on a conceptual framework we can then ask the following key questions:

How does the coach affect this process of information transfer?
How can we improve the performance of this transfer process?

1.2 Context: Innovation

The need for coaching, the need for understanding how it works, and how it can be improved, can be best understood in the specific context, coaching was observed in. Visitors from other engineering contexts are often shocked when they see how design is being practiced in our design culture. Specifically seen from a European design tradition, the process here is often seen as highly chaotic and devoid of methodological approaches. We therefore see it as important to give a brief description of the design-engineering/design-thinking approach practiced here, which, applied to the right tasks, yields highly innovative results. This specific design-engineering/design-thinking approach can best be described in the context of a Stanford course in Mechanical Engineering titled: "Global-Team Based Design Innovation with Corporate Partners". In this paper this course will be referred to as "engineering.310". Figure 2 compares the design-engineering/design-thinking approach to the traditional engineering-design approach by focusing on the tasks they are targeting, and the approaches they are using, in order to solve theses tasks.

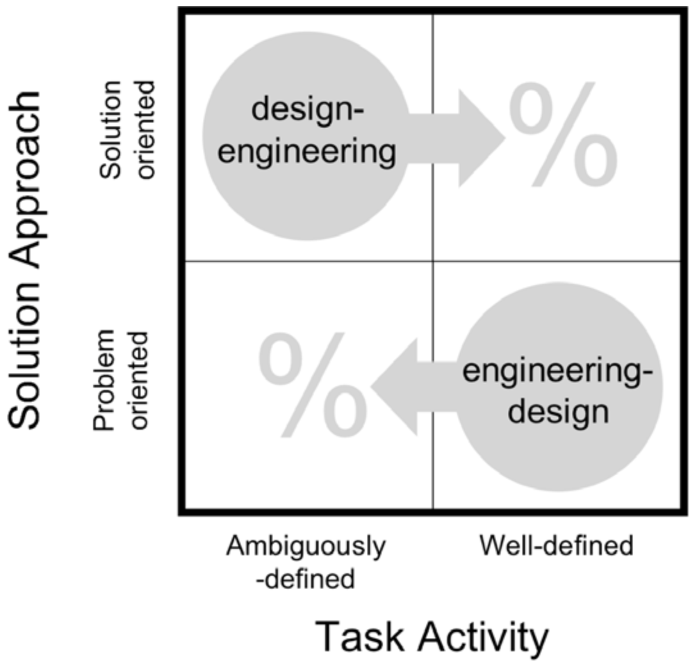

Figure 2. The matrix compares the design-engineering/design-thinking approach to the traditional engineering-design approach by focusing on the tasks that are targeted, and the approaches that are used to solve theses tasks. The matrix proposes that traditional engineering-design approaches, that use highly problem oriented methods, produce the best results when applied to well-defined tasks and less satisfying results when applied to ambiguously-defined tasks. The design-engineering/design-thinking approach is more solution oriented and yields innovative results when applied to ambiguously-defined tasks. The matrix further suggests that the approach should shift from more solution oriented to more problem oriented with a problem shift from ambiguously-defined to well-defined.

Figure 2 distinguishes between two types of tasks as endpoints of a continuum: Ambiguously-defined and well-defined. One can see this task axis as temporal too, as many projects start with an ambiguously defined task that is more and more refined as the project progresses. In an ambiguously-defined task, the variables are unknown. If one regards a task to be ambiguous, one assumes it to be infinite. Many human centered design tasks can best be approached if they are considered to be ambiguous. An example for a highly ambiguous task can be taken directly from engineering.310, where students were asked to "design something that establishes a symbiotic relationship between the driver and the car". In a well-defined task, the variables are known, the desired outcome is clearly described. Well-defined tasks are often regarded as uncertain, which based on the assumption that they are finite. Many purely technical design tasks can best be approached as well-defined and uncertain tasks. A well-defined task could be to redesign a valve according to precisely defined performance parameters.

Figure 2 also distinguishes between two types of approaches as endpoints of a continuum: Problem-oriented and solution-oriented. Even though many features of the two approaches overlap, we think it is possible to place them on opposite ends of a spectrum. In an exaggerated way one could say that problem oriented approaches rely on the idea that design problems are finite, and that they can be understood entirely through careful analysis. Assuming that the problem is uncertain and therefore finite, many methods of this approach (such as QFD or FMEA) focus on reducing complexity in order to reduce uncertainty. This complexity reduction is often accomplished by dividing the design problem into multiple partial problems. Solution focused approaches are characterized through a development of both the solution and the problem over the course of a project [6]. As the project develops, the problem becomes more and more well defined. This approach accounts for the learning that occurs during the course of a project. A solution focused approach often uses multiple iteration cycles and

various on-the-spot experiments [7] to advance the project. The goal of this approach is not to reduce complexity but rather to maintain it while managing ambiguity.
Figure 2 further suggests, that there is a mapping between tasks and approaches that leads to optimal results. Well-defined design tasks can best be solved with a traditional problem-oriented approach. Ambiguously-defined tasks, however, can best be solved through more solution oriented approaches. Ambiguously-defined tasks often occur in early, conceptual stages of new product development projects. Our observations and the research described here focuses on this specific task and approach context, which is referred to as design-engineering/design-thinking. Engineering.310 is a course at Stanford that specifically focuses on applying deign-engineering/design-thinking.

1.3 engineering.310 – "Global-Team Based Design Innovation with Corporate Partners"

A brief description of this particular course is necessary to understand the following parts of this paper. In engineering.310 high performance engineering design teams create innovative solutions to ambiguous design problems through a process that is facilitated through rich social interaction and physical on-the-spot-experiments [7]. Every year about 30 to 40 students are organized into 10 to 12 teams and work for 3 quarters on industry sponsored "real-world" design problems. Designers approach the task through a simultaneous development of both the problem and the solution rather than through a systematic problem oriented approach [8]. All students are at the Master's level and about half of them have typically several years of industry experience. The engineering.310 approach is focused more towards the early and conceptual stages of a design process. The outcome of this process is a clear set of requirements that describe an innovative product and a prototype that proves the validity of these requirements. A further description of the course can be found in [9]

1.4 Digital library content

The framework proposed in this paper was mainly inspired by studies on the use of digital libraries in a design re-use context. It is therefore important to understand the specific nature of the library content. Most of the content has been collected during previous engineering.310 design projects and exists in the form of videos, pictures, emails, and text. The content was collected to allow students access and re-use of previous design knowledge. Three aspects characterize this content: Much of it is informal, tacit, and highly contextual. The material is hardly structured, and no efforts have been made to reedit the content. Most of the content is just a collection of videos, pictures, and documents that have been collected and created by the design teams over the course of a project. Thus the content often can only be understood in the context of the project it was created in.

2 DEVELOPMENT STEPS TOWARDS A CONCEPTUAL FRAMEWORK.

The development of the proposed coaching framework is described in three steps. The entire development took place in the context described above.

Step 1: As the first step a laboratory study to investigate the usage of digital libraries in design is described. In this study we developed a basic information flow framework. The laboratory environment was clearly defined, allowing us to track the flow of information from different information sources to the process more easily. The information flow framework serves as the basis for the coaching framework.

Step 2: The second step describes observations that were made in a classroom study to explore the transition of the digital library systems into a classroom environment. The transition into the classroom allowed us to investigate usage of the systems in a more realistic and complex environment. The discoveries and observations made here are the basis for the proposition of a framework to describe and explore the important role of the coach.

Step 3: The last step employs a conceptual, exploratory approach. Based on our observations and the information flow framework in step 2, we propose a conceptual framework that allows investigating and improving the role of coaches as an important link between an information system and a user.

2.1 Step 1: Laboratory Study

The goal of the laboratory study was to investigate whether designers would use a video library with highly informal content and how this would affect the design process in comparison to the usage of a text based library. The laboratory study was based on content, which was created during a two-week warm-up exercise of the engineering.310 class, called the paper-bike experience.

Figure 3. The engineering.310 loft during the paper-bike exercise and an example of a finished paper-bike. The paper-bike experience intends to familiarize the students with the engineering.310 approach. It further functions as a team building and process awareness experience. The experience culminates in a “race-event” where the teams prove the success of their designs.

The paper-bike experience serves as an introduction into the class. Students have to build and race a bike made entirely from paper materials. The exercise gives an introduction into all major aspects of the class. The developed concepts are represented through physical prototypes, video recordings, and sketches. The design rationale is captured formally through Wikis, idea-logs [10], and a report that is written at the end of each quarter.

2.1.1 Methods

A detailed description of the setup of this study can be found in [11].

<u>Subjects:</u> Five student teams of two students each were recruited for the laboratory study. All Subjects were graduate students in mechanical engineering at Stanford. None of the subjects had taken ME310 before.

<u>Task:</u> The task was based on a two-week long introductory exercise of the engineering.310 class in which students in teams of 3-5 build and race a bike that is entirely made out of paper materials. The engineering.310 paperbike-exercise has now been conducted for several decades and therefore a considerable amount of past knowledge is available in form of informal videos as well as written reports. This rich collection of documentations makes this exercise extremely suitable as a source for a redesign task. For this study the subjects were asked to redesign the wheel of one of the previous paperbikes that had failed during the race. Documentation about the failed design and other designs was provided through a digital video library and a digital text library. Access to these libraries was voluntarily. The students were given 2 hours to complete the task.

<u>Digital Libraries:</u> Two digital library systems were the focus of this study: SMET and Informedia. SMET is a web-based digital library that allows for rich indexing [12]. The documents in SMET were indexed on the paragraph level based on an adapted DEDAL taxonomy [13]. A set of 10 written reports was indexed and provided through this system. Informedia is a digital video library that transcribes the audio track of a video into a text file. The text file then serves as an index into the video and thus allows a user to search videos using a standard text search interface [14]. The content was a collection of footage that had been recorded over the past 10 years of the paper-bike exercise. The videos were categorized and processed into the Informedia system. Overall the content amounted to about 10 hours. A detailed description of how Informedia was configured and used in this study can be found in [14].

Data collection: Each entire study was recorded through four video cameras. A screen capture tool was used to record any activity performed on the digital library systems. Sketches made during the activity were digitized and stored. A recorded interview was conducted with the subjects after the exercise was finished.

2.1.2 Results

To analyze the collected data a simple framework was developed, that considers three levels to track the information flow from an information source such as a digital library. The aim was to track the flow of information from a source to the designer who interprets it and finally to the process where it is implemented.

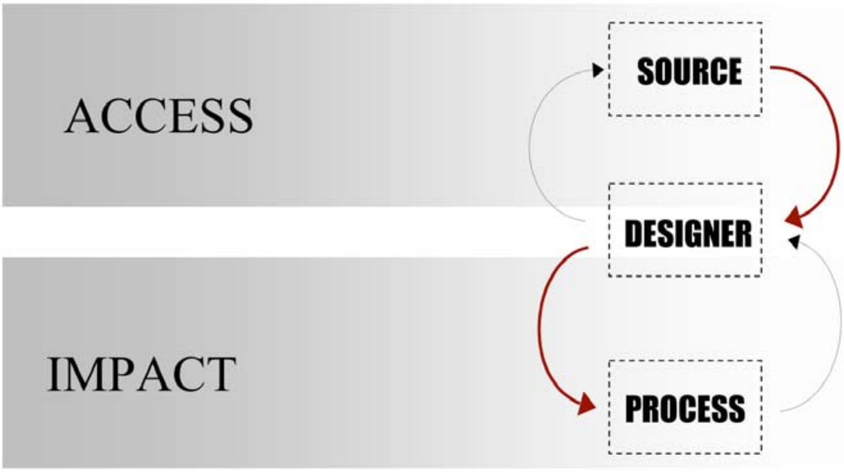

Figure 4. A three level information flow framework. The red arrows show the information flow starting from an information source, through the designer to the design process. The grey arrows track the information as it is captured by a designer and documents it in a report.

This framework also allowed a distinction between “access” and “impact” to describe the “usage” of a digital library.

- *Access:* In the context of this paper access is defined as the information flow between the source and the designer or design team.
- *Impact:* Not all the information that is accessed is actually used in the process or affects the process directly or indirectly. In the context of this paper impact is defined as the information flow that affects the design process.
- *Usage:* The combination of “access” and “impact” defines Usage as the overall flow of information from a source to the process.

The following paragraphs give an exemplary application of the framework through its application to one dataset of the laboratory study. The remaining 4 datasets are still being analyzed.

Access: Access of the digital library systems was measured through the content attention time [11]. Content attention refers to a subject interacting with information contained in the text-based design documents, video clips, or the WWW.

Table1. Access duration by type of information source. The digital video library was accessed during 15.9% of the duration of the entire study [11].

Access type	Access duration	
	(sec.)	(% of total time)
Text-based documents in SMET	1575	24.9
Video clips in Informedia	999	15.8
WWW	484	7.6
All information sources	3058	48.3

We observed that all but one of the five teams accessed the digital video library during the study.

Impact: Impact of the digital library systems was measured by tracking the migration of concepts into the design process of the team. Concepts were defined as potential partial solutions to the given design problem. . Examples of concepts were: "Use of laminated discs with holes for weight reduction" or "Paper Wedges inserted between the two Rims around the Wheels to compress the Outer Inner Rim in place".

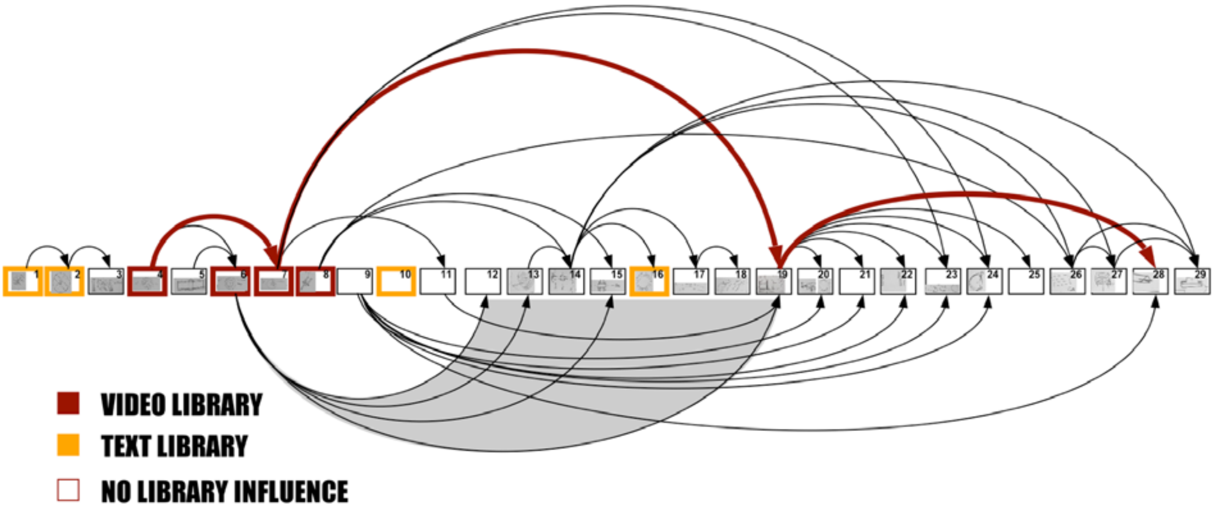

Figure 5. Concepts generated by a design team in sequential order. The arrows indicate influence on concepts further downstream. The shaded area highlights the links that indicate the "width" of a particular concept. The thick arrows indicate the "depth" of a particular concept. A detailed description of this data can be found in [11].

Analyzing links between concepts provided a possibility to measure impact. In this context "width" can be defined as the number of child-concepts that were directly inspired by a previous concept. "Depth" can be defined as the number of generations a concept was inherited downstream.

Table 2. Impact width and depth by type of information source.

Source	Impact	
	Avg. width	Avg. depth
Text-based documents in SMET	0.5	0.5
Video clips in Informedia	3.25	4.5

An interesting finding of this study was, that even tough the text library was accessed much longer than the video library, it had only a fraction of the impact. This confirms the usefulness of the framework in distinguishing access and impact. However it is important to note that this data represents only the analysis of one experiment and cannot be generalized.

2.2 Step 2: Classroom study

For the classroom study the digital video library was transferred into the engineering.310 classroom setting for the entire duration of the paperbike exercise. This study was an initial exploratory investigation of the effects of this transition: Would an informal library of videos be used in a more complex, realistic scenario? A detailed description of the setup of this study can be found in [15].

2.2.1 Methods

Subjects: As subjects we recruited two student teams for the entire duration of the paperbike exercise. Both teams were enrolled normally in engineering.310, but that our research team shadowed them throughout the exercise. Each team had 4 members.
Task: The task required the team to build, test, and race a fully functional bike made entirely from paper materials. The task was slightly modified from previous paperbike tasks. The duration of the exercise was about three weeks including several days at the end to complete a written report.

Digital Libraries: The digital video library Informedia was installed on a separate desktop computer in the classroom and made available for the entire class. The setup of the video library remained the same as in the laboratory study. In addition the students had access to a Wiki containing records of past paperbike exercises as a standard resource of the class.

Data collection: Two researchers, one of them the author, followed a design team each to support and observe their design process throughout the entire challenge. The researchers served as design process coaches for these two teams. In the class coaches are seen as a resource and don't have any influence on the grading of a design team. This is important to note as the teams interaction with the coach was completely voluntarily. This participation as coaches allowed us to gain valuable and detailed insights. More formal data was captured by the queries that were typed to search the digital video library. Finally interviews and questionnaires were conducted to gain further insights into the individual information usage behaviours.

2.2.2 Results

The following paragraphs describe our observations regarding usage of the digital video library in the classroom environment. Access and impact were not measured directly in the classroom and are therefore assessed based on direct observations, interviews, and questionnaires.

Access: The following observations were made regarding the shadowed design teams.

- During the first several days of the exercise the video library access was sparse.
- Students accessed a multitude of other resources (paperbikes from previous years, old reports, peer designers, teaching assistants) to satisfy their information needs.
- Physical resources were preferred during initial conceptual stages.
- Upon suggestion of the coach the digital video library saw increased usage. Students reported browsing the library and accessing content for several hours.

The following describes a typical example interaction that led to an increased usage of the digital video library. In this scenario the coach suggested the team to look at a specific video from the previous year that showed how a certain bike performed during the race. The coach knew the content of the library and the context it was recorded in. The coach knew that the particular video showed the bike that performed best during the previous exercise and could give that information to the team. The particular stage of the teams design process was known to the coach and a relationship between team and coach had been built.

Impact: After completion of the exercise the students were given a questionnaire in which the were asked to report how much they thought the different information sources had contributed to their final design.

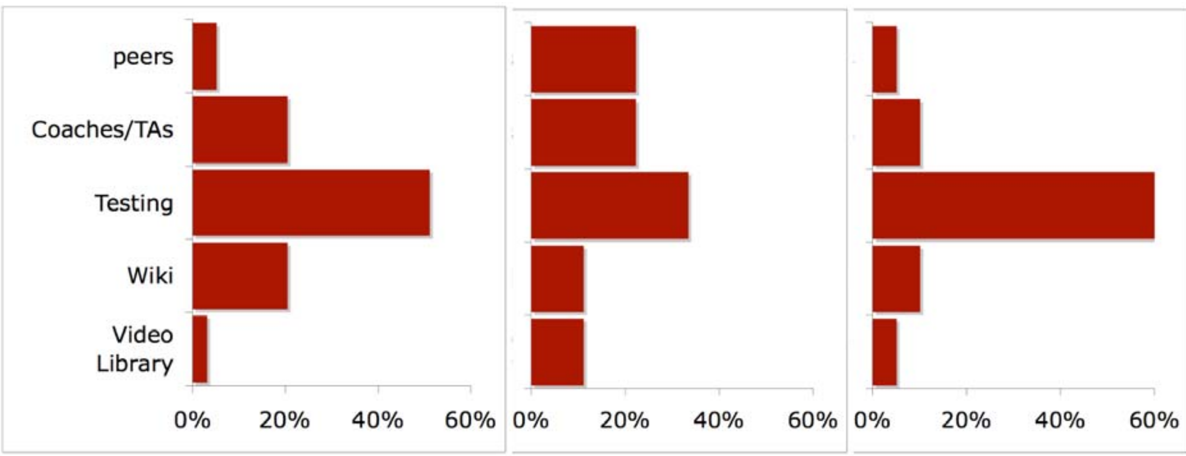

Figure 6. Questionnaire based reports of three students based on the question to what extent they thought a particular information source had contributed to their final design [15]. The results also show high differences between individuals.

2.3 Step 3: Knowledge coaching framework

In the two studies described here, two completely different usage scenarios regarding the same video library emerged. The video library was used in the controlled laboratory environment but was initially almost ignored in the complex classroom environment. However we found that a successful intervention of a coach can increase usage. The observations made during the deployment of the video library in the classroom suggest the assumption that designers select their information sources based on how they perceive them. The next paragraphs elaborate this suggestion.

Perceived accessibility:

In a study with engineers Gerstberger and Allen concluded that information channel access is dependent on perceived technical quality but mainly on perceived accessibility [16]. Bishop [17] also refers to perceived accessibility of an information resource as a primary determinant of the extent of its use. According to Bishop the accessibility of information resources "is usually assumed to depend on a range of cognitive, social, and physical factors, such as whether a person is aware of a resource, has the knowledge and skills needed to access it, and has the resource close at hand". Culnan also confirmed the important role of perceived accessibility in selecting among available information sources [18].

Perceived ease-of-use and perceived usefulness:

The theory of Reasoned action [19] and the Theory of Planned Behaviour [20] both establish a connection between perceptions and behaviour. In both theories intentions predict behaviour whereas the intentions themselves are determined by perceptions. With the Technology Acceptance Model (TAM), Davis took the Theory of Reasoned Action and applied it to the acceptance of information systems [21]. TAM uses perceived usefulness and perceived ease-of-use as determining factors of actual usage. The Technology Acceptance Model was designed for a scenario in which a group of potential users were exposed to a new information system for a short amount of time. From a questionnaire given to the subjects after the interaction, the model allowed to predict future usage. Thong applied this model to the usage of digital libraries [3].

Effect of coaching on perceptions:

The previous research described above supports the stated assumptions about the link between perceptions and usage of a digital video library. According to the technology acceptance model, the successful usage of a digital library system in the laboratory should have predicted usage in the classroom. However the technology acceptance model predicts usage in a static scenario such as a product management system in a warehouse. The observations in the classroom led to the assumption that the coach increased usage by altering the teams' perceptions towards the digital video library. By suggesting specific content from the video library to the designers the video library was perceived more useful and therefore able to compete with the other resources in the loft. For example designers did not regard videos of previous presentations as very interesting. However when the coach pointed out that a particular presentation had received the best grades in the class, the same video was perceived more useful.

A conceptual framework for knowledge coaching:

By taking the dynamics described above into account, a conceptual framework is proposed. According to this framework, the way an information source is perceived, is not only dependent on the source, but also on the interaction of a coach. A coach can directly affect perceptions of ease-of-use and usefulness of an information source to stimulate usage and knowledge transfer. Perceptions affect both access and impact. The framework suggests that an increased usage of an information source is accomplished by driving both access and impact.

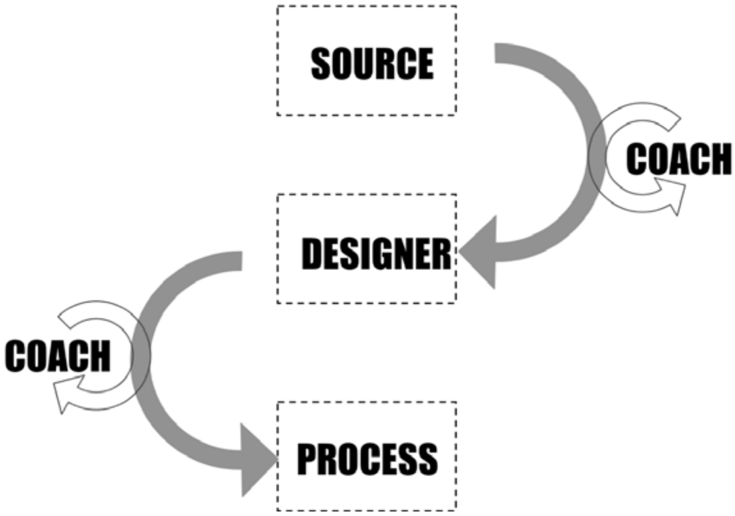

Figure 7. A framework for knowledge-coaching of designers in using information sources. A coach powerfully affects usage by driving access and impact.

Applied to the observations made in the classroom, the interaction of the coach was successful because the coach was able to stimulate both access and usage. By motivating the students to access a particular video and by explaining how the video can be accessed, the coach altered the student's perception and "drove" access. The coach "drove" impact by adding context to the accessed information, thus facilitating the overall flow from the source down to the process. This successful facilitation was based on the close integration of the coach with all three levels of the framework:

- The coach knew the entire video collection of the digital video library and the context these videos had been recorded in.
- The coach was familiar with the design team and had established a trusting relationship.
- The coach knew the process state the team was in and knew from past experience what steps would follow next.

Taking all three levels into account, the coach was able to suggest the right content and present it within the right context to the design team so that it was perceived more useful than other sources of information at that particular moment.

3 CONCLUSION

3.1 Implications for research

In our laboratory study it has shown to be a useful tool for the analysis of digital libraries by distinguishing between access and impact. The knowledge-coaching framework highlights the role of the coach in facilitating access and impact of information sources by affecting the perceptions of usefulness and ease-of-use. The framework allows asking questions regarding the appropriate interactions and factors and how they affect perceptions.

One way to look at the effect of the coach is by distinguishing between mediation and moderation effects.

- *Moderation* can be generally defined as a process in which a qualitative or quantitative variable affects the direction and/or strength between an independent variable and a dependent variable [22].
- *Mediation* can be generally defined as a process in which a given variable accounts for the relation between independent and dependent variable. [22]

The coach has direct moderation effects by increasing the information flow between the information source and the process. Mediating the source and therefore changing the way in which the designers perceive an information source, achieves this increase in usage. The successful mediation and moderation are again dependent on various factors, which remain to be isolated in future research.

3.2 Implications for practice

The framework has direct implications for coaching and the training of coaches. We believe, that the performance of a coach in increasing usage of information resources can be increased, if the coach is integrated on all the levels:

- The coach needs to know the content of a digital library and the context the information was created in.
- The coach needs to establish a trusting relationship with the design team.
- The coach needs to know the design process of a design team and be able to predict upcoming steps.

If these initial guidelines are followed, a coach can infer information needs from a design team's process, and guide the team towards valuable resources. A trusting relationship allows the coach to increase impact while a deep insight into a team's process allows inferring information needs.

3.3 Overall findings

The laboratory study revealed that a digital video library can be a useful resource to support a design team. The distinction between access and impact in analyzing the information flow gave interesting insights, as we found that high access does not necessarily lead to high impact of accessed information on the process. The main findings of this study however emerged out of the transition of the digital video library from the laboratory into the classroom. The video library had been used in the controlled laboratory environment but in the more complex classroom environment it remained initially unused until the intervention of a coach. The transition gave valuable insights into the effects of successful knowledge coaching of digital libraries and led to the development of a knowledge-coaching framework. The proposed framework is highly speculative and still remains to be tested and validated. We therefore suggest to use the Technology Acceptance Model but by applying it at discrete time-points during the exercise. By doing this it might be possible to study designers' perceptions towards a particular information source at different times using different mediation and moderation techniques. However the idea, that a successful deployment of an information source such as a digital library, is not dependent on the quality of its interface alone, but can be facilitated by trained coaches, gives many new opportunities for the deployment of information resources. Shifting a few resources into the appropriate training of coaches might lead to better results in a shorter time than focusing on interface development alone.

4 ACKNOWLEDGEMENTS

This research is funded by the National Science Foundation under Grant No. 0230450. The authors would like to thank Helen Chen and Zhen-Hui Eng for assisting with the survey, and the teaching staff of ME310A course in Stanford University for providing access to the course resources and the students.

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