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Education E-Village:
Empowering Technology Educators in Developing Regions

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1. Abstract

There exists a significant need for relevant, accessible and useful resources to enhance technology education in developing regions [1] [2]. Currently, access to courseware for technical subjects such as Computer Science is available several online resources [3] [4]. However, these resources are designed for developed communities, where technology is ubiquitous, technology infrastructure is robust, and educators have easy access to a variety of academic publications and other helpful guides. Therefore, the available online resources do not provide sufficient avenues for educators in developing regions to understand the courseware or discuss alternative ways of teaching it based on their specific constraints. To address this deficit, the TechBridgeWorld group at Carnegie Mellon University initiated the "Education e-Village" (E-Village) project. E-Village is an online community where educators from around the world will be able to share ideas, experiences, expertise, educational resources, and strategies to promote and enhance technology education in developing regions.

This senior thesis project enhances the search functionality and user experience of E-Village. We analyzed existing search solutions and chose the Open Source search engine Lucene for integration as it met our needs best. To enhance the user experience, we followed both heuristic evaluation and user-testing approaches. In order to perform user testing, we created electronic mockups of features based on structured essential use cases [5]. These included modified screenshots and mockups of the current E-Village design and commonly used websites. Finally, we conducted these usability tests with a representative sample of 18 users. We compiled a list of problem areas and user preferences, and addressed them in a set of recommendations. The focus of the improvements was to make the user interface (UI) as intuitive as possible, while staying consistent with user expectations.

2. Introduction

There exists a significant need for relevant, accessible and useful resources to enhance technology education in developing regions [1] [2]. Currently, access to courseware for technical subjects such as Computer Science is available several online resources [3] [4]. However, these resources are designed for developed communities, where technology is ubiquitous, technology infrastructure is robust, and educators have easy access to a variety of academic publications and other helpful guides. For example, they assume the presence of resources such as a good internet connection to download course materials such as videos and lecture slides, and materials needed to build robots in a robot programming course. Although these resources have a mechanism for general feedback, there are no avenues to collaborate and adapt a course to a region, or to figure out if substitute materials can be used. Upon facing any issues with courses, there are no avenues to get in touch with the authors. Therefore, the available online resources do not provide sufficient avenues for educators in developing regions to understand the courseware or discuss alternative ways of teaching it based on their specific constraints.

To address this deficit, the TechBridgeWorld group at Carnegie Mellon University initiated the "Education e-Village" (E-Village) project. E-Village is an online community where educators from around the world will be able to share ideas, experiences, expertise, educational resources, and strategies to promote and enhance technology education in developing regions. Educators will benefit from course materials and curricula made available by members of the E-Village community, contribute their own resources or ideas towards

extending and evaluating existing resources, share best practices relevant to teaching computing technology in under-resourced settings, seek or offer advice on particular topics or issues, and learn about publication opportunities, conferences, funding sources, professional organizations, and other opportunities for advancing their educational offerings and professional growth.

The goal of E-Village is to empower younger generations in developing communities to become create technology solutions that would be useful in their immediate communities. We are focusing on post-high-school level because in most developing regions, students are not introduced to technical courses until they reach University level. We are focusing on technology courses due to the ease of their application and impact in the immediate communities [1] [2] [6]. Core costs of communication and computing have dropped significantly over the recent past and are at a point where they can be deployed to have immediate and large-scale impact [1]. Currently, a team of researchers at both Pittsburgh and Qatar campuses is working on different aspects of E-Village. This project is being sponsored by Yahoo! under their Yahoo Technology for Good grant.

3. Thesis Goals

My thesis is involved with 2 critical aspects of E-Village - search functionality and User Experience (UX).

3.1 Designing Search Functionality

Users of E-Village should have the ability to search for specific information and obtain accurate results in a reasonable amount of time. E-Village will contain information in different formats such as courseware, a discussion board, and general information. A further complication for E-Village is that many people who access this content from developing regions will be using low-bandwidth and often flaky internet connections so the search capabilities need take these parameters into account. Finally, internet access in developing regions can often be very costly. Hence, an efficient and effective search capability is essential for the success of E-Village.

As E-Village grows, it will become especially important that search results are quick and accurate. For example, a user who is looking for information on mobile robots might expect to see information under courseware, relevant topics that have been discussed on the discussion board, and a method to contact other technologists who have experience with this topic. Users might also require an option to look for things within a certain realm of information such as limiting the search to a specific geographical location or range of dates. A simple iterative search will often be ineffective in such applications and instead, a search function with indexing and data mining components will become essential to maintain effectiveness.

Therefore, to select an effective search option, we analyzed the different parameters and constraints for E-Village and rated the different options for search based on this analysis. We first determined what areas of E-Village should be searchable, how relevance should be assigned after performing user studies (see section 7.2). Other important aspects were determining how search results should be presented to users, when "Advanced Search" functionality should be presented, and what kinds options should be provided for advanced search.

3.2 Designing User Experience (UX)

According to the Nielsen Norman Group,

> "*User experience encompasses all aspects of the end-user's interaction with a company, its services, and its products. The first requirement for an ideal user experience is to meet the exact needs of the user, without fuss or bother. The next requirement is that products are defined by simplicity and elegance making them a joy to own, a joy to use. True user experience goes far beyond giving users what they say they want, or providing checklist features. In order to achieve high-quality user experience in a company's offerings there must be a seamless merging of the services of multiple disciplines, including engineering, marketing, graphical and industrial design, and interface design"* [7].

The User Interface (UI) design greatly influences how a user experiences web applications. In the case of E-Village, it will be critical that information is organized effectively and made available to the user in an easy-to access format. A preliminary interface for E-Village with basic functionality has already been implemented by TechBridgeWorld students and staff. We critiqued this initial design to assess its effectiveness in characteristics such as conveying information in a useful manner, ease of navigation, and efficient use of space. Our critique is informed by two types of Human-Computer-Interaction methodologies and by initial feedback from usability tests with relevant TechBridgeWorld partners who will ultimately be the primary benefactors of E-Village. These tests were conducted to determine the effectiveness of specific areas of the current prototype, and to evaluate potential features. Once our critique was complete, we identified areas for enhancement, and made detailed recommendations for the new design.

4. Related Work

In this section, we review existing solutions and methodologies that are relevant to our work. First, we describe work done on education in online communities, and the challenges that come with it. Second, we describe specific projects that are currently being used to serve purposes similar to that of E-Village. Third, we describe work that guides the design of interactive technology, specifically in web usability. Finally, we outline work that has been done on usability testing. As a major proportion of E-Village users are expected to be in remote developing regions, we focus on literature relevant to remote usability testing methodologies.

Regarding learning in online communities, Renninger and Shumar assert that learning and change in virtual communities is increasingly interdependent with learning and change in the participants' local institutions [8]. Stakeholders from these local communities are needed to channel them into a virtual community. The authors cite that using external mentors incentivizes students to learn. For example, a student may be given an assignment to write a business plan, and the critique by his teacher will be expected and likely be ignored as part of the grading system. But the critique received from an external businessperson will be viewed as authentic. Due to the experience of the external person, the critique is likely to be taken more seriously by the student. Also outlined are reasons for failure of online education communities. Some of these are that such communities are slow growing and need time to mature, traditional internet tools do not facilitate collaboration, the presence of technological gaps and limitations, and the lack of experience in teachers

planning or leading online activities. Finally, the authors conclude that access to collaborative tools such as discussion boards provide social support but do not create a sense of community. In most cases, a sense of community emerges only when educators, researchers, and scientists start working together on compiling educational materials.

In another study related to virtual classrooms and communities, Neal finds that communication in class has several aspects including engagement and involvement [9]. The use of a variety of collaboration technologies provides richer communication than any one of them alone, and helps to foster a sense of community as found in a physical classroom. The technologies evaluated include videoconferencing, audio conferencing, Internet Relay Chat, NetMeeting, virtual worlds, and modes of asynchronous communication. Neal mentions benefits of distance learning such as being able to experiment with technologies, minimal travel for the instructor, and the ability to bring in guest lecturers with no additional travel expenses. However, the amount of time needed for the instructor to prepare was higher due to the overhead caused by having to schedule meetings, contact students, and updating materials on the website.

The MIT OpenCourseWare (OCW) project is a web-based dissemination of MIT course content. Courseware is freely available to anyone in the world. OCW was started in 2002 by the Massachusetts Institute of Technology (MIT) to spread knowledge and educate students through the Internet [3]. By 2009, the site had 1950 published courses in more than 35 academic disciplines. Although there is a mechanism for general feedback, OCW does not provide access to any MIT faculty. According to the OCW site, each published course requires an investment of $10,000 to $15,000. This is used to compile materials from professors, ensure proper licensing, and converting the materials in a format that can be globally-distributed. Courses with video content are estimated to be twice as expensive as regular ones. OCW is being used successfully by educators, students, and self-learners for a wide variety of purposes.

The Open.Michigan project is an initiative by the University of Michigan (U-M) aimed at creating and sharing knowledge resources and research with the global community [4]. It was started in 2007 by the U-M Medical School as a move towards a more open education process. 10 academic departments within U-M are currently participating in the initiative. The site provides general directions to contact various departments within U-M regarding materials, and pointers to avenues to share educational resources. There is a facility to provide general feedback on a course but no platform to discuss issues with courses. Open.Michigan uses open content licensing, and encourages the use, redistribution and remixing of educational resources.

Project aAqua is a Q&A forum where people can post agriculture-related questions and get them answered by certified experts [10]. It was started in 2003 by Developmental Informatics Laboratory (DiL) of IIT Bombay, to provide an avenue for farmers in India to get their questions answered by experts. The certified experts include professors, deans and other credible authorities for information. As of September 17, 2009, there were 9393 members, 17 forums and 8769 topics being discussed. There are forums on crops, animals, agriculture recommendations, market information, prices and farmer schemes. In a poll conducted on the site, 85% votes indicated that users wanted to use aAqua on their cell phones. Registered users are sent “free” crop tips to registered users via cell phones.

In *The Design of Everyday Things*, Norman discusses usability principles by discussing poorly designed objects that are encountered in daily life [11]. He argues that good design "must explain itself," and describes four principles of good design. These include (i) Visibility - user can tell what the state of a device is, and what actions are available; (ii) Good conceptual model - the presentation of operations and results is consistent, and feels part of a natural process; (iii) Good mappings - relationships between actions and results should be easily determinable; (iv) Feedback - user should receive full and continuous feedback about the results of actions. Although these principles are described with commonly-used physical devices, they can be applied to anything that requires human interaction.

A good amount of work has been done on web usability. Most notable are works done by Krug, Nielsen, Loranger, and Tahir. In *Don't Make Me Think*, Krug lays the foundation for his first law of usability stating that websites should not have elements that make users think and distract from the task at hand [12]. Actions available on a site should be self-evident and intuitive. He also provides frameworks for conducting quick and cheap usability tests. In *Homepage Usability*, Nielsen and Tahir argue that the homepage is the most important page on any site, and make the case that special attention should be given to it serves as the entry point to a site [13]. They provide detailed descriptions of homepage usability, and an evaluation of the homepages of 50 commonly used websites. In *Prioritizing Web Usability*, Nielsen and Loranger report results of their extensive user testing, and critique real-world sites for legibility, navigability, searchability, appropriate design and other usability factors [14]. Finally, Nielsen outlines ten general principles for user interface design that can be followed as guidelines [15].The combination of these resources gives a good understanding of web usability principles.

In terms of remote usability testing, the literature is very sparse. In their work, Dray and Siegel outline the advantages and disadvantages of both synchronous and asynchronous modes of remote testing [16]. In synchronous methods, the test facilitator manages the test and receives data from the participant, who is remote, in real-time. In asynchronous methods, there is no interaction with the facilitator and there is no real-time date being received. One major disadvantage with asynchronous methods is that they do not collect real-time observations, and are hence limited to self-reporting and the biases that come with it. In related work, Thompson, Rozanski and Haake make the case that synchronous remote testing using software such as NetMeeting, WebEx, Lotus Sametime, and WebQuilt, can be as effective as traditional in-person testing to identify usability problems [17]. Finally, Nielsen describes a mathematical model for finding usability problems, which can be used to plan the quantity of user testing to achieve varied levels of problem-finding [18].

5. Initial Implementation of E-Village

The initial E-Village implementation was performed on the OpenCms Content Management System [19]. We switched to Drupal [20] due to better developer-support and ease of maintenance. The preliminary implementation of E-Village had an initial UI design and contained materials relevant to two courses for testing purposes. We envision the development of E-Village through three distinct stages:

(i) Pre-Pilot:
This stage determines the high-level requirements for functionality of E-Village, and broadly

specifies its design. Usability tests and interviews with a representative sample of our target users inform the needs and preferences that drive this design. By the end of this stage, all critical functions such as search and course submissions are fully specified, and an informed prototype for the UI is designed. This thesis completes the pre-pilot stage of E-Village.

(ii) Pilot:
During this stage the design and functionality specified in the pre-pilot stage are implemented and this pilot version of E-Village is launched for longer-duration tests with a selected group of first users. The usability tests at this stage will determine the final design and steady state operations of E-Village (see 'Future Work').

(iii) Post-Pilot:
This is the steady-state stage of E-Village where the online community is available to everyone online with tested features and functionality.. Occasional usability tests and feedback from users will drive any further enhancements as the needs arise.

6. Search Functionality

On any website, having useful search functionality is essential. When users are looking for something on a site, they mainly use either the navigation menus or search. Most users type one, two or three words into the search box to look for something and expect useful results [14]. As search functionality is commonplace these days, users have also formed mental models of what search should return. With the wide use of highly-optimized web search engines such as Google, users' expectations of search have increased tremendously [21]. Hence, it is very important that users' search experience on a site is favorable.

There are a number of benefits of having a search engine to look for information on a site. They can be used to understand what is important to users and tune the site accordingly, to satisfy users' mental model of having a search box on each site, and to set up automatic indexing mechanisms for dynamic content [22]. Internal site search has several advantages compared to a world-wide web search. Some of these advantages described by Nielsen and Loranger are [14]:

- Site search deals with a smaller set of pages compared to search engines for the entire web.
- User studies can be performed to understand users and their intentions.
- The importance of documents is well known. So the relevance rankings can be prioritized as opposed to being computed by web search engines.
- More metadata can be accessed, allowing site search to learn more about document relationships.

Due to the advantages of having a site search, we determined it would be best to find a suitable search engine, and customize it for E-Village.

6.1 Solution Requirements

In order to determine which solution would be optimal for E-Village, we enumerated a list of requirements that addressed its constraints:

- *Efficiency*: Solution would consume a reasonable amount of resources, and be able to return results quickly.

- *Supported content types*: Solution should be able to work with common content types including file formats such as HTML, PDF, TXT, and Microsoft Office.
- *Inherent limitations*: Solution should not have any limitations that would hinder the growth of E-Village in the long run.
- *Cost*: Solution should preferably be free or have minimal cost of setting up and maintenance.
- *Platform dependency*: Solution should be able to run on popular operating systems including Windows, Macintosh and Linux.
- *Offline functionality*: Solution should provide mechanism to allow users to search and save search results offline. This could be useful in areas where internet connections are less reliable.
- *Availability of documentation*: Solution should have sufficient documentation available freely. It should have a mechanism for support in case we encounter problems. These could take the form of books, online tutorials, and developer communities.
- *Ease of integration and management*: The solution should be easy to integrate within popular CMS software.

6.2 Solution Analysis

In our quest for the best search solution for E-Village, we looked at both Open-Source solutions and various commercial site search service options. The Open-Source solutions consisted of free search engines that could be integrated into E-Village. In this category, we looked at Lucene, Sphinx, and the Xapian Project [23] [24] [25]. The site search services are free or paid search services that would index the content on a site and return results based on processing that is done at the service's expense. In this category, we looked at Google Custom Search Engine (CSE), FreeFind and PicoSearch [26] [27] [28]. Among all these solutions, we looked more closely at Lucene and CSE as they were the most popular and offered the most in terms of functionality in their respective categories. The following table illustrates the comparison between Lucene and CSE:

Feature	**Lucene**	**CSE**
Supported file types	Text, Rich Text Format, XML, HTML, Microsoft Word, Microsoft Excel, Microsoft PowerPoint, Adobe Portable Document Format	Adobe Portable Document Format, Adobe PostScript, MacWrite, Microsoft Excel, Microsoft PowerPoint, Microsoft Word, Microsoft Works, Microsoft Write, Open Document Format, Rich Text Format, Shockwave Flash, Text.
Search indexing limit	Unlimited	5000 annotations, which represent inclusion of URL or URL pattern e.g. including the URL www.foo.com/ and all its subpages would constitute one annotation; including the URL pattern www.foo.com/*bar (which includes all pages in this domain with 'bar' in the URL) also constitutes one annotation.
Cost	Free	Free

Platform dependency	Platform independent	Platform independent
Offline functionality	No	No
Availability of documentation	Documentation is highly fragmented and disorganized. Main sources are Drupal site, Lucene site, online forums, and books on Lucene.	Clear and detailed documentation available on CSE site for both beginner and advanced users. Also included are tools like Google Marker to include other sites in search results.
Ease of integration and management	Implementation will be more involved, and search will require optimization and maintenance once implemented.	Does not require much upkeep once implemented. Availability of easy-to-follow documentation facilitates this.

Both solutions supported the essential file formats, were available at no cost, were platform independent, and did not possess any kind of offline functionality. Therefore, the primary difference was that Lucene had unlimited indexing whereas CSE had a limit of 5000 annotations after which you have to either remove documents from your index, or monetarily increase the limit. Even though the CSE limit of 5000 annotations would easily satisfy E-Village needs in the near future, it would limit us in the longer term, especially if the activity and content on the site increased drastically. In terms of documentation, CSE had better centralized resources compared to Lucene whose documentation was fragmented. Also, integration and management in Lucene would be more involved. However, Lucene had a supportive developer community. We also determined it would be best to have control over the search on our server, as search services could change their policies unexpectedly. Given these factors, we selected Lucene as the search engine that would be the best fit for E-Village.

6.3 Selected Solution: Lucene

Lucene is a simple, high-performance and powerful full-featured text search engine. It has the ability to perform field searching and add new indexed content without regenerating the entire index. It is a software library that can be integrated into various applications. Being a Java library, it is very flexible compared to other applications [29]. It provides the ability to search in many different languages, to perform date-range searching, and extended field searching i.e. focusing on a certain field e.g. Title, Author, or Content. MIT's OpenCourseWare uses a Lucene search engine at its backbone [30]. Zend Framework has a PHP port of Lucene that can be plugged into Drupal search. As we are using Drupal to run E-Village, this is very useful.

In his Pisa lecture, Cutting does a good job of outlining the architecture of Lucene [31]. The Lucene Architecture consists of four major abstractions: Document, Analyzer, Indexer, and Searcher. A Document is a sequence of Fields, where each Field is a <*name*, *value*> pair. Here, *name* is the name of the field e.g. title, author, content, etc. and *value* is the text (data) that it maps to. An Analyzer is a TokenStream factory, where each TokenStream is an iterator over Tokens. A Token is a tuple <*text*, *type*, *start*, *length*, *positionIncrement*>. Here, *text* is the data text in the document, *type* categorizes the text, *start* and *length* are offsets in characters, and *positionIncrement* is typically set to 1. The Indexer maps Terms to <*df*, <*docNum*,

<*position*>*>*> tuples. Here, Term is a <*fieldname*, *text*> tuple, *df* is the Document frequency, *docNum* is the Document ID, and *position* indicates location within Document.

Lucene uses a B-tree based inverted indexing strategy [32]. This has the advantage of updating in place and fast searching once indexing has been completed. Inserts and lookups on B-Trees are O(log n) operations. Lucene takes a slightly different approach in the way it indexes. Instead of maintaining a single index, it builds multiple indexes and merges them periodically. An index is built for each document, and these indexes are merged periodically to keep the number of indexes small so that searches are quick [33]. In Lucene's algorithm, a stack of indexes is maintained. For each new document, an index is generated and pushed onto the stack. The following pseudo code [31] illustrates this incremental merging algorithm [31]. Here, b is the merge factor and M is set to infinity:

```
for ( size=1; size < M; size *= b ){
      if ( there exist b indexes with size docs on top of stack ){
            pop them off the stack;
            merge them into a single index;
            push the merged index back onto the stack;
      }
      else {
            break;
      }
}
```

Fig. 1 below illustrates how this works with an example. Here, b=3, 11 documents have been indexed, the stack has 4 indexes, and 5 merges have taken place. The grayed indexes have been deleted.

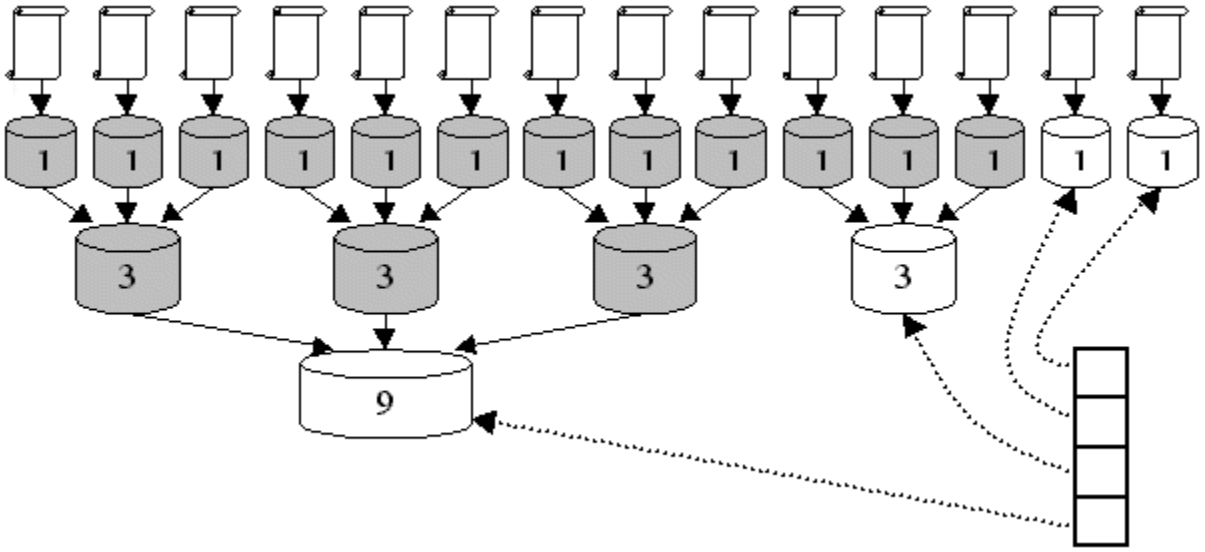

Fig. 1 Lucene Indexing Algorithm [31]

Lucene's search algorithm maintains a queue of posting streams, where each posting is a <*Term*, *Document ID*, *Weight of Term in Document*> tuple [34]. The following pseudo code was inferred from Cutting [34].

```
While ( there are posting streams remaining in the queue ){
      Calculate score for each posting in stream;
      Merge postings of each Term in query;
      Keep top k ranking documents only;
}
```

7. User Experience

The targeted E-Village users could belong to any of the following combinations of background and exposure to technology:

Developed region, high-exposure to technology	Developed region, low-exposure to technology
Developing region, high-exposure to technology	Developing region, low-exposure to technology

We expect most of the users to belong to the top-left and bottom-right quadrants. According to Jakob's Law of the Internet User Experience [13], users spend most of their time on other websites. The accumulated amount of time spent on other sites will greatly outnumber the amount of time spent on our site [14]. Users who have a good exposure to technology prepare their expectations from a site based on previous experiences on other sites. If they are accustomed to prevailing design standards, they will expect to encounter similar conventions on E-Village. Hence, it is not worth making them work hard with a deviant user interface. Additionally, for users who may not have had a good amount of exposure to technology, it will become important that the UI is intuitive and easy to follow. It should not have any elements that require the user to think for a while before figuring out how to accomplish a task, or elements that distract users from performing the task at hand [12].

Our principal goal in designing the E-Village user experience, therefore, is to ensure that the UI is consistent with expectations of users with good exposure to technology and intuitive enough for those with a lower exposure. Users should be able to navigate E-Village without a difficult learning curve. We followed a two-pronged approach on enhancing the UI of the preliminary implementation of E-Village. First, we take a heuristic evaluation approach which builds on work done by leading web usability experts. Second, we perform feature-specific usability tests to understand preferences and user habits of our target user group, and evaluate potential features. In both these testing methods, the goal is to find and document as many usability problems in a UI so that they can be addressed in future versions [18]. Finally, we use the results obtained from both approaches in conjunction with knowledge gained through our literature review to enhance the UI and the overall UX in E-Village.

7.1 Heuristic Evaluation

Heuristic evaluation is a discount usability engineering technique used for quick, cheap and easy evaluation of a user interface design [35]. It involves having a set of recognized usability principles ("heuristics") that can be used to evaluate the effectiveness of a UI. The UI is examined to see if it adheres to each principle as part of an iterative design process. It is the most popular usability inspection method. The idea here is to utilize work that has been done by leading web usability experts to enhance the UI of E-Village.

We used the work done by Krug to synthesize a set of usability guidelines that we could use as benchmarks [12]. For example, a sample guideline was designing pages for scanning, not reading. This included the attributes, using clear visual hierarchy, using conventions unless the new conventions do not confuse in any way, breaking up pages into clearly defined areas, making it obvious what is clickable, and ensuring low visual noise. Each attribute was evaluated on a 1-point scale. For each attribute, the scoring of E-Village was as follows:

- 1.0 - if the site met the attribute requirements completely
- 0.5 - if the site met the attribute requirements partially
- 0.0 - if the site did not meet the attribute requirements at all
- N/A - if attribute was not applicable to the site

We did not assign the number of points available to each attribute on any scale of relative importance. The reasoning was that the number of attributes that we could find under each guideline would indicate how important the guideline was. The goal in designing this scoring system was to figure out where E-Village is lacking in usability, and devise improvements for each attribute that needed them. The following table summarizes how the preliminary implementation of E-Village was evaluated against these guidelines:

Guideline	**Score (%)**
Designing pages for scanning, not reading	80%
Ensuring choices available to users are not ambiguous	50%
Using concise language	50%
Designing persistent navigation considering the 5 key elements: Site ID, Sections, Utilities, Home, and Search	80%
Designing page names	100%
Showing users where they are on the website through the use of appropriate indicators	0%
Using navigational indicators	0%
Using tabs for navigation	N/A
Designing content for homepage	50%
Getting the message across on the Home Page	0%
Designing pull-down menus	N/A

Although the prototype was at a rudimentary stage, it received a score of 62% indicating that there was room for significant improvement. These heuristics would also be influential when designing the UI, to ensure that it satisfies them.

7.2 User Testing

Although heuristic evaluations are good at judging an interface and uncovering problems with it based on design principles and past studies, they do not tell us anything about our target users. In order to make the UI effective for our target users, we need to understand their preferences, tastes and concerns. User testing is an interface debugging technique where real users are given a set of tasks and observed as they interact with

the system in order to perform the tasks [18]. In the case of E-Village where users have varying backgrounds and exposure to technology, it becomes important to conduct some form of user testing.

7.2.1 Testing Constraints

Our target user group consisted mainly of professors who have busy schedules, so in order to perform user testing, we had to consider 3 main constraints: (i) the tests should be conducted within a reasonable amount of time (ii) the tests should not require participants to perform any preparation on their side e.g. installing additional software, etc., and (iii) the tests should be consistent for both in-person and remote tests. The traditional method of user testing involves the use of a usability lab where test participants are audiotaped and videotaped as they perform tasks on a system [17]. This typically involves an administrator to run the test with the user, and a group of usability professionals who observe from behind a one-way mirror. This approach yields the best results but involves significant time investments, high costs and setting up infrastructure. Effective remote usability testing techniques mainly involve the use of software that allows shared screen capabilities [17]. This means that the participant's screen and cursor can be viewed by the test administrator. However, this involves the installation and setting up of additional software. Finally, as E-Village is currently rudimentary, we needed to determine ways of evaluating both the existing UI, and potential features that would be implemented during the Pilot stage.

7.2.2 Test Design

We had to use a methodology for testing that was feasible within the constraints outlined, but allowed us to test features that were not implemented yet. Hence, we decided to employ a synchronous technique [16] by using screenshots of our existing UI, and creating mock-ups of potential features that could be expected on E-Village. Our in-person testing method was inspired from the low-cost version of traditional user testing described by Krug [12]. To address testing users remotely, we decided to synthesize the mockups in a portable format that could be easily transmitted to the participant. We could then call the participant through low-cost calling services, such as Skype, and walk him/her through the mockups. In each testing method, we would use "thinking-aloud" as a way of testing our mockups [36]. Here, study participants would be asked to speak continuously about their perceptions of the mockups. Also, follow up questions could be asked on the mockups to get an understanding of user values.

At this stage, it is important to get both high-level and detail-oriented feedback from users. We wanted to get both open-ended feedback and answers to specific questions from the users. In both cases, it was important that users were honest and open in their feedback. So, we decided to purposely give the mockups an "unfinished" look and make users understand that the UI and features of E-Village are not finalized. These mockups would also include (edited) features found in commonly used websites. In this way, they would feel like they are a part of the design process and be comfortable in giving honest opinions on things. We created the mockups using Adobe Illustrator, and stored them in a PDF file. Each sheet would have a single mockup. In this way, users could be asked questions relevant to that particular mockup preventing the chance of jumping ahead and looking at other mockups.

7.2.3 Designing Test Cases

We set the test limit to 30-45 minutes, and hence it was important for us to scope our test areas down. To this extent, we selected the following areas of the UX for testing:

- *Overall Navigation*: This decides how easy it is for a user to find something on the website. It includes the four aspects, (i) navigation and menus, (ii) category names, (iii) links, and (iv) information architecture i.e. how information is organized.
- *Collecting User Information*: The kind of information collected from users will become critical for the success of E-Village. Ask for sensitive information, and users will become skeptical about the site. But with the right amount of information, a sense of community can be fostered.
- *Registration*: This determines how easy it is for users to sign up.
- *Login*: This determines how the user would log into the site, and the mechanisms that would need to be in place if users forgot their passwords.
- *Search*: This is a prominent part of the UX on any site.

We then created electronic mockups of features based on structured essential use cases [5]. These types of use cases are the most robust in the face of changing technologies because they "model tasks in a form closest to the essential nature of the problem" and do not mix design solutions with the problem description [5]. A key highlight of these use cases is the clear division between user intentions and system responsibilities. We used this form of use cases to avoid any inherent biases among ourselves in designing the solution, and to look out for unexpected solutions or paths taken by users to achieve their means. Fig. 2 below shows the header mockup of the existing UI. Fig. 3 below shows the mockup of the search results page taken from Monster.com.

Fig. 2 Mockup of header

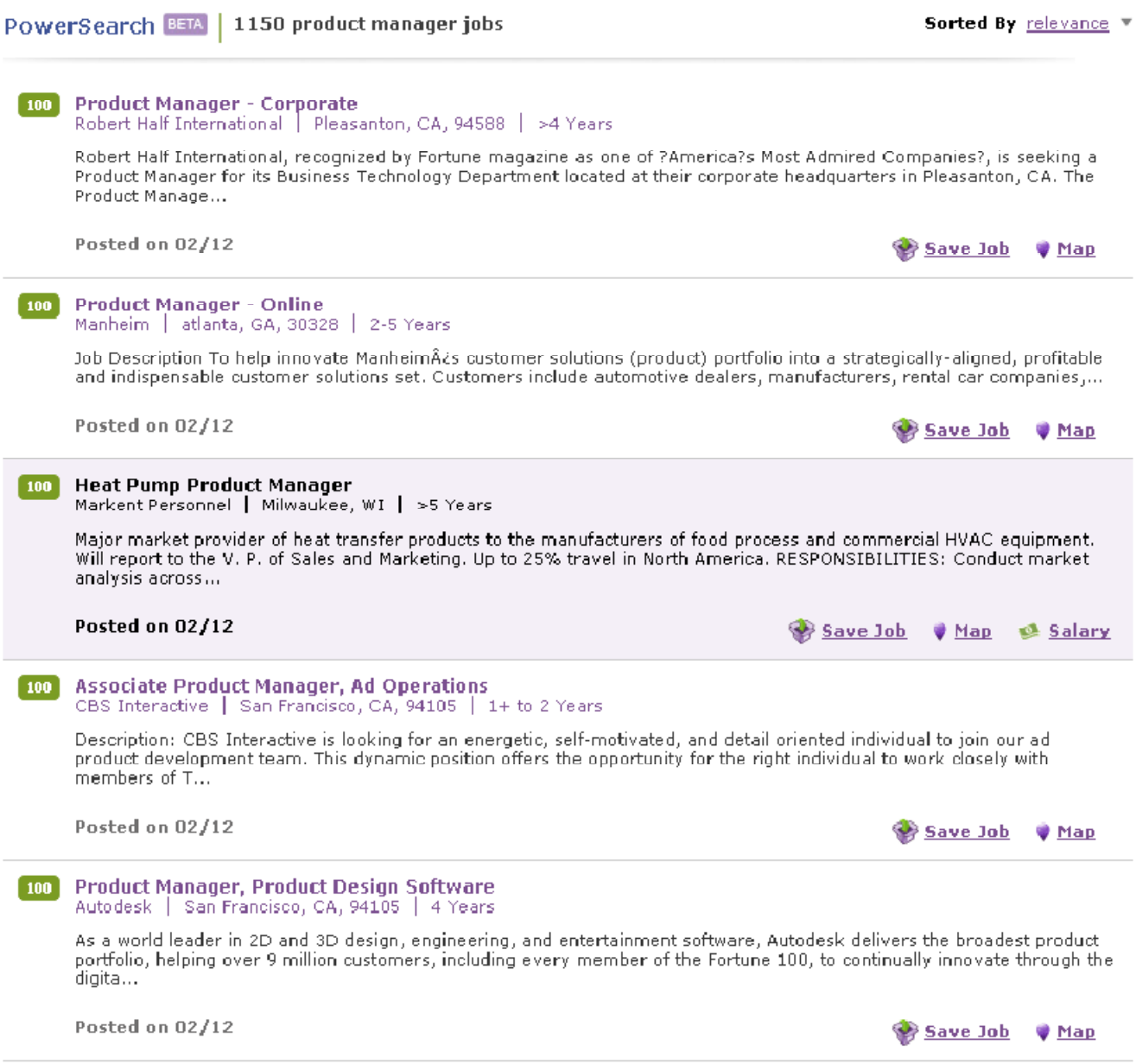

Fig. 3 Mockup of Search Results

7.2.4 Selecting Test Participants

In order to get useful feedback, we need to test with multiple users. By testing only a single user, there is the risk of being misled by the behavior of the user who may perform some actions by accident or in an unrepresentative manner. If the website has several distinct groups of users, testing should be performed with multiple users [37]. As E-Village is currently in its pre-pilot stage, we wanted to get as much feedback as possible. Hence, we contacted and setup user tests with 18 of TechBridgeWorld's contacts. These comprised a mixture of in-person and remote user tests, and were carried out in conjunction with Saurabh Sanghvi (ECE '10).

7.2.5 Test Setup

The in-person tests were conducted in a private setting in the form of a small room. The room was well-lit and a dual screen monitor setup was used. A video camera was placed to capture the monitor and to record the conversations. However, the video would only be used if the users consented to it. At the start the monitor, would be blank. The facilitator would then run over the administrative requirements, and obtain the participant's consent. The participant would then be asked a few background questions before delving into the mockups. The participant would then be shown mockups one-by-one and asked questions relevant to them. At the end, they would have the opportunity to ask any questions or offer feedback on the process.

8. User Testing Results and E-Village Enhancements

Among the three approaches to design, we are using a conservative approach i.e. we treat design as a scientific or engineering process involving methodology and control [38]. In order to ensure that we did not develop any personal biases while administrating the user tests, we did not look at any of the test data before we had collected it from all of our participants. After we collected all the data, we analyzed the data from each individual user in the framework that we had developed before testing. The following are the results obtained for the tests conducted on each mockup:

8.1 Header Mockup

For the header mockup shown in Fig __, 50% of users had negative comments, while 50% were indifferent towards the header. The fact that nobody had positive comments, and the large number of negative reactions indicates that the header will need major restructuring. Overall, users complained that the header took up too much space, the E-village title formatting was distracting, the top links were hard to read, and the placement of the Carnegie Mellon and TechBridgeWorld logos was "confusing." Hence, the following enhancements are recommended:

- The current header is taking up too much space. On a 15" laptop, it would occupy about 20% of the screen, which is a lot of valuable space. Reduce the current size of the header in terms of height.
- The navigation links are currently above the title. This causes a lot of users to miss them. Change the header so that the navigation links are below the title, closer to the body and content of the page. This would save the user that extra distance needed to be covered to click on the navigation links, as they would not need to cross the title each time.
- Users have mixed opinions about the ribbon. It does not seem to add any useful functionality or aesthetics, but adds some amount of complication in terms of the design implementation. Discontinue use of the ribbon and replace with a linear bar.
- People were irritated by the title due to the inconsistencies in coloring and formatting. The title includes both red and black colors, and E-Village is spelt with a lowercase "e." Change the title to read "Education E-Village" and use one color for the font. Instead of the current font, a standard font that is easy to read on the screen should be used e.g. Helvetica, Gill Sans, or Verdana.

- The links at the top are hard to read as they are too small and too close, and white text on red background is hard to read. Reading it is especially hard under poor resolutions. Increase the font size, lighten the background and use a screen-friendly font such as Helvetica, Gill Sans, or Verdana. Increase the width of the bar.
- The combination of logos is confusing. It is hard to infer if this is a Carnegie Mellon site or a TechBridgeWorld site. Reduce the size of the TBW logo and group the logos together so that there is no confusion.

8.1.1 Intuitiveness of Top Links

At least 83% of users found 'Home', 'About', 'Courses', 'Feedback', and 'FAQ' to be intuitive. However, 50% of users found 'Workshops' to be non-intuitive and 94% of users found 'Submit' to be non-intuitive. Hence, the following enhancements are recommended:

- Users understand that a 'Home' link brings you to the homepage. Retain the link. Also, ensure that clicking on the E-Village logo brings you to the site homepage, and that hovering over it says 'Home'.
- It is useful to have the 'About' link to help users get detailed information about the site. Retain this link. It could be relabeled to 'About E-Village' depending on how the text fits in with the design. It should include information about E-Village such as the project goals, who is working on it, and how it is funded. Each of these should be under separate headings as opposed to a paragraph form, for better readability.
- Most of the activity on E-Village is expected to be within courses. So retain the 'Courses' link.
- 50% of users found the 'Workshops' link to be non-intuitive, which raises concerns that it is unclear what the workshops are for. Either mention what the workshops mean on the homepage or place it at a secondary level of navigation. Also, if 'Workshops' is not a core feature, remove it from the top navigation and place it at a different level on the site.
- 94% of users found 'Submit' to be non-intuitive. Place the submit functionality under the courses tab and remove it from the top navigation.
- Although there were no major concerns with 'Feedback', it will likely not be used as much on the top level of navigation and does not have the same value as the other links. Remove 'Feedback' from the top navigation, place general feedback link at bottom of site, and course-specific feedback under each course homepage link.
- 100% of users found 'FAQ' to be intuitive. However, the general use of acronyms on websites is discouraged. Relabel 'FAQ' to 'Help' as it is consistent with conventions that are used on users' favorite websites. Under this link, it is essential to have most asked questions about E-Village. It should be placed at the top right of the page.
- For each link, when user is on the respective page, the link should be highlighted and unclickable e.g. on homepage, Home link should be highlighted and unclickable
- The number of top links is given by 5±2. Although the number of links can be below this limit, it should never exceed this.

8.2 Sidebar Mockup

72% of users understood the sidebar model. 50% of users had negative comments on the sidebar, whereas 44% of users were indifferent to it. The low percentage of users who had a positive reaction (6%) indicates that the sidebar will need major improvements. Some of the user complaints were that the parts on the sidebar were not differentiated properly, the fonts were distracting, the search box was too small and in the "wrong" place, the bottom links were confusing, and it was unclear what could be done without logging in. The following enhancements are recommended:

- Overall
    - The fonts need to be consistent across the page. Use a screen-friendly font such as Lucida, Tahoma or Verdana.
    - Links are not justified. Users tend to read from left to right in most languages so format the links so they are aligned towards a left margin.
    - The curves at the bottom of the sidebar do not add any additional aesthetic or functional value but create complications in implementing the design. Discontinue use of the curves at the bottom and make the sidebar continuous till the bottom.
    - Consider using a different color as the font is hard to read on a poor resolution.
    - The sidebar should be used only when necessary. For example, it is useful to have the sidebar when user is viewing a course as you could have links based on the course on the sidebar. However, the sidebar is not very useful on the homepage as it takes up valuable space.
- Search Box
    - The current search box is too small. Upon typing one or two words, the user is unable to see what the first word typed was. Increase the size of the search box so that it can accommodate 25-30 characters. Inside the box, display 'Search'. This will be replaced by the query that the user types. Use a magnifying glass icon instead of a button called "Search".
    - Search box is currently in a non-intuitive place and users find it hard to locate it. Place it at top right of page preferably in the navigation bar, where it is easily accessible.
- Bottom Links
    - Bottom links are not indented correctly. They should be flush left i.e. indented with a left margin.
    - A number of users had issues understanding what the bottom links on the sidebar map to. Either discontinue use of the sidebar model completely and use top navigation or adapt the links on the sidebar to the content being viewed. The latter option is more useful as it gives the flexibility to provide context-dependent options to users i.e. when users would find them useful.
    - The presence of "Other materials" link creates a bit of confusion. Other materials should be paired with regular materials with an indication on why they are different materials e.g. a video icon next to material name if the material is in a video form.
- Login

- 'New User' meaning is unclear. The option should instead be called 'Sign Up', 'Create Account' or 'Register'.
- The Login button can be retained but the text boxes should be changed. We should have a text box with 'Email' written inside of it and another one with 'Password' written inside of it. This will make more efficient use of space. The fonts in the text boxes should have a relatively lighter color.
- Login box on sidebar seems unwelcoming as you are prompted to login to do anything. Remove the login box from the sidebar and place it on the top right side of the page. There are 2 options (i) place the login boxes on the top right corner with an option to register an account or (ii) place a link to login on the top right corner and either give a popup login box (as used by Twitter.com) or take the user to a different page. In this case, it will become important to ensure that the user does not lose any work if he/she was in the middle of a task.

8.3 Course Homepage (Layout)

17% of users had positive comments on the page, 50% were indifferent towards the page, 33% had negative comments. 89% of users were able to understand the layout quickly. For the most part, users appreciated the simple, clean layout. Key user complaints were that the text was too dense, it was unclear what this page was and where on the site the user was, the header and sidebar color combination was distracting, and the content of the page did not have a structured layout. The following enhancements are recommended:

- Users like the "fairly uncluttered" interface. In future designs ensure that the course homepage is clean and the number of distracting objects is minimized.
- Some users were unsure if they wanted to login or register account. Provide the benefits of logging when users are likely to register e.g. on a course page, users could encounter a 'favorite' feature. But being able to favorite courses requires the user to register.
- Either keep navigation vertically on sidebar or horizontally on top but not both. Having both sidebar and top navigation bar seems to cause confusion as to which one you should be following. The top navigation bar is preferable as it leaves space on the page for content. This allows for a sidebar to be shown where it could potentially be helpful e.g. on a course page.
- There is no way to find out where user is on the site. Highlight the specific tab on the navigation bar to indicate which area of the site user is on. Also, add breadcrumbs just above the body (content) heading to indicate where user is on site.
- The placement of logos is causing confusion as to who owns the site and what the role of each party is. Remove the TechBridgeWorld logo from the header, and place it in one of the information boxes on the site homepage. This could be a box introducing the user to E-Village and could feature the TechBridgeWorld logo in it. Additionally, have copies of the Carnegie Mellon and TechBridgeWorld logos at the bottom of the page in the footer. This gives us enough space to credit the agencies and not take up real estate on the content or navigation area.

- A majority of users did not like the color combinations. The site will be predominantly red to be consistent with the Carnegie Mellon and TechBridgeWorld colors. A color palette similar to those used on Cmu.edu or Cornell.edu could be used.
- Justify the links and text in the content to be flush-left i.e. aligned with a left margin. Especially in the case of the content text, this facilitates the flow of language and enhances readability due to the random edge on the right.

8.4 Registration Page Mockup

17% of users had positive comments on the page, 6% of users had negative comments, and 77% of users had indifferent comments. The fact that users did not have any major complaints about the page indicates that the page is fine for the most part. The most common irritation that users faced was the request for birthday information. Some users confused the Google reference thinking that they would need to login with their Gmail account. However, this confusion would be resolve upon explaining that some of the mockups were edited versions of features found on popular sites. The following enhancements are recommended:

- A number of users expressed irritation and concern upon seeing that the birthday was being asked. This indicates that users value their personal information, and anything that requests that kind of info without mentioning the reason behind it will lead to a drop in credibility of the site. The registration screen should only ask for information that is absolutely necessary for registration.
- Password strength checker is overkill. Instead just mention that password should be a certain number of characters.
- Some users had confusion whether each field is required. One option is to add a line saying that each field is essential but then valuable screen space is taken. Instead, do not mention that each field is required, display an error message if the user tries to proceed without filling in the required information. The error message should contain highlighted field(s) that the user did not fill in.

8.4.1 Entering Given Number of Fields

83% of users were fine with filling in the given number of fields. In the mockup, the user had to fill in 6 boxes including the Captcha. Keep the number of fields required at a maximum of 6-7.

8.4.2 Entering Captcha

72% of users were fine with entering the Captcha. These are necessary to protect against spam, and should be retained on the registration page.

8.4.3 Collecting User Information

Most users were comfortable most types of information. However, majority of users were not comfortable supplying information that could be considered personal, such as birthday or contact phone. The following enhancements are recommended:

- 89% of users were fine entering their real name. Keep this field but relabeled to “Full Name”.

- 89% were not comfortable entering their birthday. Remove this field as it does not seem to serve any kind of purpose. It adversely affects the UX with the users being skeptical of the site.
- 61% were comfortable entering this information on the site. Some users cited concerns of gender discrimination. This field should be removed as the information is not really useful for the purpose of effectively participating on the site.
- 94% of users were fine entering their profession, due to the 'professional' nature of the site. This field should be retained.
- 72% of users were comfortable supplying their employer information. This information could be optional, and users could be prompted for it at a later stage.
- Users were evenly split on supplying work address information. There seems to be no useful reasons to have this information so remove it.
- 100% of users were fine with supplying their contact information. This field should be retained.
- 72% of users were not comfortable sharing this information due to its personal nature and privacy concerns. Remove this field.
- Users were evenly split on supplying their profile picture. As having a profile picture could serve as a substitute for face-to-face communication, this field should be kept. However, it should be optional and the user should be requested for it at a later stage.
- Of the above fields, the ones that should be prompted during registration are Current Email Address (indicating that this will be user ID), Full Name, Choose a Password (indicate minimum length), Re-enter a Password, and Captcha. All of the fields should reveal what the purpose of the site is for. It is very important to keep it professional and only include things other users would find useful.

8.4.4 Reading Terms of Service (TOS)

72% of users indicated that they were unlikely to read the TOS. As the TOS is necessary for legal reasons, and to inform users how their content is managed, it should be retained. However, it should be concise and made scannable by breaking the text up into headings with paragraphs or bullets. Also, below the TOS box, there should be a statement such as “By clicking on Accept, I am agreeing to …”. This saves the user from having to perform an additional click.

8.4.5 Building Profile

55% of users were highly likely to build their profile and 22% would build it later on once they are comfortable with the site. Profile is an important step in bringing users back to the site, and establishing trust in the community. Hence, users should be able to enter certain pieces of professional information about themselves that could be useful for other professionals in the field. This includes information that was deemed as optional in section 8.4.3. 83% of users wanted to fill this information later on after registration. Allow users to fill in this information later under their account settings. They could be sent an email initially asking them to fill in this information. Another option is to display a blurb after registration asking users to build their profile. The user should have the choice of filling in this information at the time.

8.5 Login Page Mockup

61% of users had positive comments on the login box and 39% of users had indifferent comments. The fact that no user had negative comments on the mockup indicated that users are familiar with it, and like clean and uncluttered design. Following are recommendations for enhancements:

- The ‘Keep me logged in’ feature does not seem very beneficial at this point, and should be removed.
- Once user is logged in, the link at the top right should change to 'Account' to indicate that user is currently logged in.
- 33% of users preferred logging in on homepage, 33% preferred logging in on separate page, and 33% have no preference. In order to avoid having the login box occupy space at the top right, have a link to login and either display a popup as used by Twitter.com or take to separate page for login.
- In order to reset their password, 83% of users preferred to have a password email sent to their account. Following a series of steps on a site requires users to remember answers to "secret" questions. This is one more additional thing for the user to worry about. If a user forgets password, a password reset email should be sent to his/her email account. This should have a link that can be clicked on to reset the password.

8.6 Search Results Page Mockup

39% of users had positive comments, 50% of users had indifferent comments, and 11% of users had negative comments on the mockup. The low percentage of negative reactions indicates that there were no major issues with the layout. The following are recommendations for enhancements:

- 55% of users knew what the numbers in the green boxes meant (relevance scores), and 50% of users would take advantage of these scores. The relevance scores in the mockup were all 100, and hence did not add any significant help in figuring out the most relevant links. This is a case that could happen in which case no useful information is added by the relevance scores. Also, we will have options that the data is sorted by (relevance, date) so the user can see that and infer how the data is being sorted. Additionally, users who do not catch the relevance scores right away will have to think for a split-second about what the number means. It would be easier to just parse the blurb of text in the search result or look at the tagged attributes. Discontinue use of relevance scores.
- 83% of users indicated interest in marking courses that they could look up later on. Allow users to mark courses from both search results and course homepages so that they can view them on their account/profile page later on. The user should be able to view what courses he/she is teaching and what courses he/she is "following".
- Sorting options should include relevance (by default) and date posted.
- Subtly highlight alternate results block.
- Each search result will be displayed in a row form, as users have a mental model for it. Within each row, there could be 2 columns. One for displaying title and short blurb, and the other one for other useful information such as date posted, level of course, etc. Matching terms from the query should be bolded in the blurb text.

8.7 Search Filter Box Mockup

28% of users had positive comments, 38% of users had indifferent comments, and 33% of users had negative comments. Some of the major concerns raised included the categories being ambiguous and the possibility of being perceived as different things. Following are recommendations for enhancements:

- 'Region' is ambiguous. Change it to something like localization or language
- During the test, users seemed to look at the categories and think about them as if they were looking at a course hierarchy under the courses link. Hence, their assessment of the filter might have been inaccurate. We would need to do some user testing once E-Village has been launched to understand user behavior once they get search results, and if they use advanced search filters.
- Additionally, course categories could be perceived differently based on the background of the user, so some titles could become ambiguous e.g. is physics a Science or Engineering course? Since we are starting off with targeting technical courses, we could use categories that reflect different areas of technology e.g. computer programming, databases, software design, machine learning, etc.
- A number of users commented that there should be a string based search, and wanted to filter by level and type of content. This could be attributed to the fact that the search results mockup before this did not show the textbox where the search query was typed. If they had seen it, perhaps they would not have mentioned the string search as you could refine your search by modifying what you had typed in. Ensure that the search results page shows the query user had typed in within the box, and allow the user to modify the query and search again.
- One concern raised was that by 'filtering' results, we might be hindering multidisciplinary discovery of courses. This is something the E-Village team will need to think about (if they want to allow filtering into such categories). At the start, we think this filter not be necessary as the number of courses will be limited and such a filter only becomes useful when you have too many results to contend with. The other case is that users want to search within certain kinds of courses (by level, etc.). In this case, it might be more useful to provide a search option under the courses page. Even otherwise, if 20 results are displayed on a page, we would not need this functionality as most results would come in a page or two (for the near future). Hence, we would worry about this only once we have a number of courses that typing in "Intro" would return 3 or more pages worth of results.
- 77% of users preferred layout 1 with the vertical filter on the left. This is mainly due to the familiarity and visual appeal. The other reason is that in the horizontal layout, the filter is at the top of the page. So it takes some space even when users may not even use it, and if a user is dissatisfied with the returned results, he has to go back all the way up to the top of the page.

8.8. Course Homepage (Information Architecture)

77% of users wanted to use the search box, and 61% of users wanted to use the courses link to navigate down to the potential courses. The following are recommendations for enhancements based on our findings:

- Most users have a mental model of expecting a list of courses. The following information should be present under the 'Courses' homepage.
    - Short intro to courses (2-3 lines)
    - Featured course
    - Default categorization of courses
    - Additional ways to view courses by tags e.g. by level, localization
- Although it is tempting to throw in the kitchen sink in terms of categories, we should realize that the number of choices for a user is l1 * l2 * ... * ln, where li is the number of choices at level i, and n is the total number of levels. Once we have a certain number of course on E-Village, it will be useful to run usability tests to find out how effective the course navigation is.
- 33% of users wanted to search by university, 72% wanted to search by topic/title/area, 17% wanted to search by region, 33% wanted to search by professor, 17% wanted to search by keyword. Lucene should be configured so that title, author and content get higher proportions of relevance rankings. Of these title should get the highest ranking.
- In order to look for a person, 27% of users wanted to use the authors link although it was pretty unclear what they would expect. 61% of users wanted to use search where they would type in
    - Name of professor
    - University name
    - Courses taught
- 11% of users did not anticipate why they would be looking for a person
- Currently, we feel that looking for a professor might not be an activity that users would be doing regularly. Once materials are being uploaded, it is likely users will be looking for courses and dealing with other course-related things. As mentioned in Paradox of Choice, providing users with lots of choices reduces the quality of the overall experience. More choice is not necessarily better. It may be taking time that could be devoted to other matters.

10. Conclusions and Future Work

In general, the approach we used to test users was effective. By splitting up the mockups into individual elements, we were able to gain detailed feedback on their usability, and ask open-ended questions to get a sense of high-level user preferences. Once the design has been implemented and content been published onto the site, usability tests will need to be run again (i) to confirm that the changes in fact fixed the problem, (ii) to ensure that new problems have not been introduced into the design, and (iii) to explore more deeply the usability of the structure of the site evaluating issues like information architecture and task flow [37]. According to Nielsen, the number of usability problems found through a usability test with *n* users is $N(1-(1-L)^n)$, where N is the total number of usability problems in the design, and L is the proportion of usability problems found while testing a single user. The typical value of L is 31%. Hence, testing with 15 users will uncover all the problems. Since testing with 5 users will uncover 85% of all problems, it is better to have 3 tests with 5 users each than to have one test with 15 users [37].

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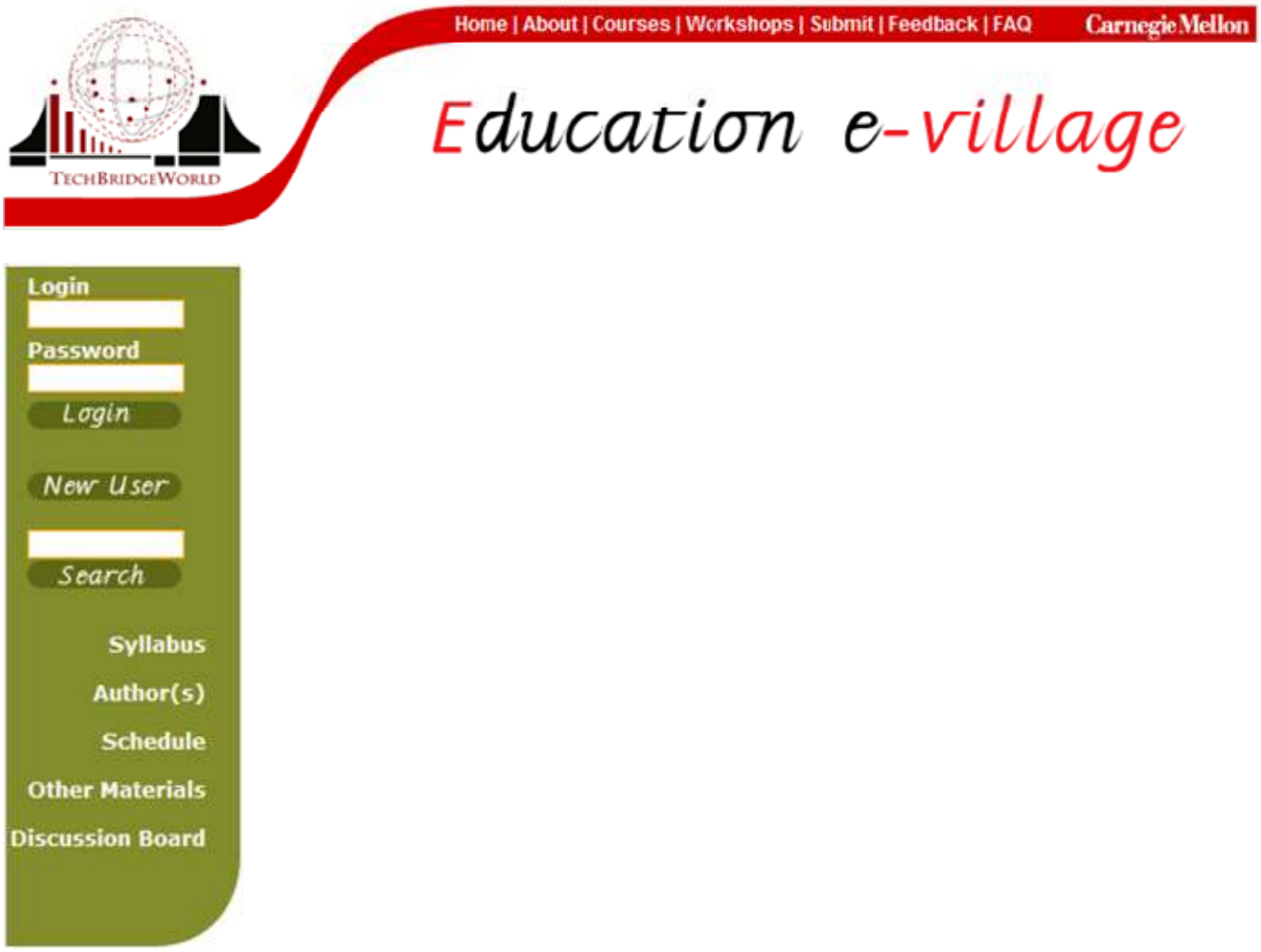
Appendix A: Usability Test Mockups



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Introduction to Robotics

Syllabus

Robotics is a field that brings together computer science and engineering, resulting in systems that interact intelligently with their environment. With applications ranging from agriculture to factory automation, from healthcare to education, robotics is a fascinating and fun way to develop creativity as well as the design, implementation, and integration skills that are essential for computer scientists and technologists.

The main goal of the course is to challenge students to think creatively and to teach them to integrate diverse areas of knowledge such as Computer Science, Design, Electrical Engineering, Mechanical Engineering and Math to create innovative systems. In this course, students will work individually and in groups to build robots using Lego robot building kits and to program them using microcontrollers. Through these projects, they will learn how to write programs that control a physical device. They will learn to read and understand research papers, to give presentations to technical and non-technical audiences, and follow a project through from an initial idea through design to implementation.

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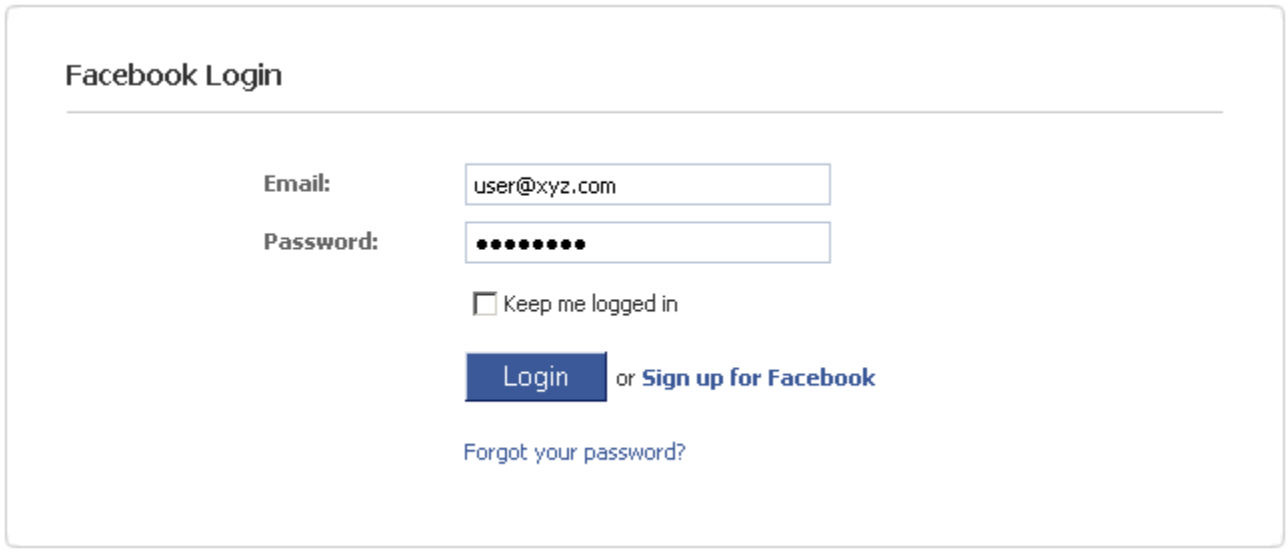
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