COLLABORATIVE DIGITAL DESIGN NOTEBOOKS

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Abstract *– Many design courses require students to maintain a paper-based personal design notebook or journal. The potential advantages of a digital notebook have been described in the literature, but few reports can be found on the use of digital notebooks in practice. This paper describes the design and implementation of a cloud-based collaborative workspace to provide a shared team design notebook. The shared workspace uses Microsoft SharePoint sites and Microsoft OneNote notebooks as the main components. SharePoint sites were created for 34 design teams in a 2nd-year engineering design course. Each site had a team notebook, document library, discussion forum, and task scheduler. Instructions and training were provided at the beginning of the course. Students were able to use the tools with little difficulty, and were able to use them as an effective replacement for a paper notebook. However, many teams did not make full use of the available capabilities, and there was little evidence of higher-level collaborative activities. The described implementation is technically and financially feasible, is scalable to large classes, and satisfies most of the requirements of a collaborative design notebook. However, scaffolding and training are needed to ensure that students collaborate effectively.*

Keywords**:** collaboration, digital notebooks, design notebooks, design education

1. INTRODUCTION

1.1 Traditional Design Notebooks

Many engineering design courses require students to keep a personal design notebook to record and explore ideas, to document individual contributions, and to promote reflection [1]. Notebooks are portable and instantly accessible, and facilitate handwritten notes, freehand sketches, and simple engineering calculations. It is common practice in many design classes to collect and evaluate individual design notebooks. In a large class, it is logistically difficult and time consuming to collect, mark and return notebooks, as only one copy exists and notebooks are bulky. It is also difficult to enforce rules that students make regular entries. Many students add entries just before the deadline.

Traditional paper-based notebooks do not effectively capture computer-based information including CAD models, email correspondence, websites, downloaded reference documents, computer-based calculations, etc. Also, personal notebooks emphasize and document individual work, not group collaboration. They are difficult to share, and reinforce the natural tendency of students to work independently rather than collaboratively.

1.2 Digital Design Notebooks

Computer-based digital notebooks have many advantages over paper-based notebooks, including easy sharing and collaboration, and easy incorporation of digital information. The potential advantages and requirements for digital notebooks have been reported in the literature for several decades [2], [3], and recently computer technology has advanced to the point where digital notebooks have become practical [4], [5], [6].

1.3 Objectives

This paper describes the design, implementation and evaluation of a collaborative digital design notebook. The goal was to see if the best currently available tools have the functionality to effectively replace the traditional paper-based design notebook, and to investigate the possibility of supporting collaborative activities within a design team. This is not a formal research study, but rather is an initial attempt to design and evaluate a suitable environment and gain insight into the benefits, pitfalls, and issues to be overcome.

1.4 Collaborative Knowledge Building

When designing a collaboration environment, it is important to base the design on accepted theories of

collaboration and collaborative learning. Researchers in the field of computer-supported collaborative learning (CSCL) generally adopt a constructivist framework [7], such as collaborative knowledge building (CKB) [8], [9]. Stahl [8] argues that CKB can be decomposed into two interacting processes: personal understanding, and social knowledge building. An individual's tacit understanding of the world evolves as internal knowledge structures are restructured to resolve contradictions and breakdowns as a result of new information. This tacit understanding must be articulated in explicit form to be communicated to others. Group understanding evolves through the sharing of individual perspectives representing personal understandings. Discourse is used to clarify meanings and rationale, exchange arguments and negotiate conflicts. A shared group understanding is articulated in explicit form. Information from the group is then internalized by individuals, and used to restructure personal understandings.

Stahl has described the necessary computer affordances required to support the collaborative activities of CKB [10]. These activities include articulating and sharing personal perspectives, comparing different perspectives, clarifying meanings, debating alternative perspectives, negotiating shared understandings, building shared knowledge structures, and formalizing knowledge in explicit form.

Many but not all of the required affordances are available in currently available tools, and there is no evidence that commercially available tools are designed based on a careful consideration of the requirements of collaboration. For example, research studies and experience suggest that collaboration tools need a facility for commenting on and discussing content of a document, without directly editing the content, e.g. [11], [12]. Effective commenting tools are implemented in some tools, e.g. Microsoft Word and Google Docs, but are absent from other tools, e.g. Microsoft OneNote.

Many studies allow students to choose their own tools and methods, and simply observe the results, e.g. [4]. However, it has been observed that online interaction does not naturally evolve into higher-order collaboration without guidance, training and scaffolding [7]. Many studies show that students generally lack collaboration skills or experience [13]. When students work in a group, they typically divide the task into individual parts that can be worked on independently and there is typically little higher-level collaboration [11]. Collaborative authoring of a document typically involves correcting grammar and minor wording problems. Rarely is the content discussed or debated [12]. However, there is research evidence that collaborative activities can be taught and supported by effective scaffolding, guidelines, examples, and descriptive rubrics [14], [15].

Many studies in CSCL also focus on text-centric tools like wikis, blogs and discussion forums, e.g. [13], [16]. These tools do not support the freehand sketches, calculations and other elements that are essential to a design notebook.

2. REQUIREMENTS FOR COLLABORATIVE DIGITAL NOTEBOOKS

In order to advance the adoption of collaborative digital notebooks, it is important to clearly define the requirements, and to design tools based on the requirements. The requirements are defined by accepted theories of collaborative learning, lessons learned in previous published research, judgement, experience and reflection gained from many years of teaching.

To be used effectively, a collaborative digital notebook should at least match the capabilities of a paper-based notebook. It should allow easy freehand input of sketches, calculations, diagrams, and notes. It should be portable, and be easily accessible. It should be possible to access the notebook from any device or platform, anytime and anyplace.

A collaborative notebook should be easy to share with members of a team, as well as with instructors. It should facilitate collaborative knowledge building, and should track the collaboration process. In particular, it should track individual contributions over time.

The collaborative notebook should provide facilities to allow students to articulate their personal perspectives or points of view, and to allow other members of the team to view and comment on their perspectives. The notebook should allow the team to debate different perspectives, and negotiate a shared understanding or group perspective in the form of an explicit knowledge structure. These collaborative activities map very well to the standard design process, where the group first negotiates a definition of the problem, then generates ideas and concepts, compares and evaluates the concepts, negotiates the best solution, and documents the solution.

A design notebook must support the multiple knowledge representations used in design, including freehand sketches, images, engineering calculations, text, screenshots, webpages, references, etc. It should be possible to organize and view the content in different ways, using search, tags, keywords, etc.

A design notebook should allow students and instructors to comment on content, without editing the content directly.

To track collaborative activities, the notebook should provide a transcript or record of activities. It should be easy to identify the content contributed by different students, and when it was contributed. It should also be easy to examine how the notebook has evolved over time.

To support the logistics of a large design class, it should be possible to access all of the team notebooks from a

single interface, and it should be easy for instructors to review and comment on progress.

3. SURVEY OF AVAILABLE TOOLS

Cloud and mobile computing have become ubiquitous in recent years, and many tools have emerged to support communication and collaboration. However, few of these tools satisfy all of the requirements described in the previous section.

Every school now employs a web-based learning management system (LMS). These systems are designed to deliver content, manage assignments, and manage course grades. Collaboration tools are usually limited to simple text-based tools like a discussion forum, blog or wiki, and LMSs lack the affordances required for a collaborative notebook.

Most students use social media to communicate with each other. Popular tools include instant messaging and Facebook. These are quick and easy, but lack the full functionality required to support rich collaboration in engineering design. The collaboration activities are also not visible to the instructor.

Many students use Google Docs as a platform for collaborative authoring. Google Docs is easy to use and readily accessible, but it lacks the more advanced functionality of SharePoint and OneNote.

Many students collaborate using popular file sharing tools like Dropbox and Google Drive. These are very useful for sharing documents, but lack full collaboration capabilities.

Many researchers emphasize the importance of freehand sketching during conceptual design, and the value of tablets with stylus input [17]. Currently, touchscreens with stylus input are available only on some Windows laptops, as well as iOS and Android tablets and phones. Mac computers are not currently available with touchscreens.

Many students use multiple different tools, switching between them as necessary. Lack of integration between tools becomes a barrier for more complex collaboration scenarios.

4. MICROSOFT OFFICE 365

After evaluating the available alternatives, Microsoft Office 365 was selected as best satisfying the requirements. Microsoft Office 365 is an integrated, cloud-based suite of tools including Office (Word, Excel, PowerPoint, OneNote, etc.), Outlook (email), OneDrive (cloud-based file sharing), Skype for Business (synchronous conferencing), and SharePoint (cloud-based collaboration).

Microsoft's Office applications (Word, Excel, PowerPoint) have become de facto standards in their categories and most people are familiar with them. SharePoint is a leading collaboration platform widely used in the business world, but it is relatively unknown in the academic world due many factors including cost, technical support requirements, lack of awareness of its capabilities and benefits, and availability of free alternatives. Very few reports can be found in the literature discussing the use of SharePoint as a platform for collaborative learning. One of the earliest applications was reported by Buchal in 2002 [18]. Miertschin and Willis used SharePoint as a Learning Management System [19]. More recently, Iinuma *et al*. investigated the use of SharePoint as a platform for CSCL [20], and their survey results showed that students found the tools easy to use and useful. However, the authors note that scaffolding is required to ensure effective collaboration.

OneNote provides all of the capabilities of a traditional notebook, with the additional benefits of a digital notebook. It has particularly strong support for freehand stylus input when used with a touchscreen device. It is generally considered to be one of the best available note-taking applications, and it is widely available as it is part of the Office suite of productivity tools. Important advantages of OneNote over competing products are its strong support for freehand pen input, and its sharing and collaboration capabilities when used with Microsoft SharePoint. The Microsoft SharePoint collaboration platform allows OneNote notebooks to be shared and collaboratively edited by members of a design team. Barber *et al*. describe the successful use of SharePoint and OneNote to support teams in a large pharmaceutical company [21].

OneNote is available on all leading platforms including Windows, Mac, iPhones, iPads, and Android devices. OneNote notebooks can be opened and edited in a browser using OneNote Online, or they can be opened in a locally installed OneNote application. All changes are synchronized automatically, and multiple users can edit a notebook simultaneously.

Microsoft offers a free Office 365 Education license to educational institutions, and many schools have adopted it as their email platform. Some schools, including Western University, have upgraded to the Office 365 Education E5 license. The E5 license includes fully installed Office applications (Word, Excel, PowerPoint, Outlook, Publisher and OneNote) on up to 5 PCs or Macs per user. It also includes the same Office apps on iOS and Android tablets and phones [22].

5. DESIGN OF TEAM WORKSPACES

Based on the requirements, a prototype shared design workspace was designed and implemented using the Office 365 suite of tools. The shared workspace was designed as a SharePoint team site with a shared team notebook, a discussion forum, a document library, and project management tools.

It is important to note that careful thought and planning are required in the design of the shared workspaces, and the recommended collaboration practices. This provides structure and scaffolding to the students, rather than letting them figure it out on their own. Very few students have used SharePoint before, so guidance is essential. Scaffolding and guidelines are also required to define and encourage collaborative behaviors.

No published best practices for using SharePoint and OneNote to support collaborative work were found, so the design was preliminary and subject to improvement. Students were encouraged to adopt their own practices, starting from the recommendations, with the hope that some good practices would emerge from experience and experimentation.

6. TECHNICAL ISSUES

While Office 365 is among the best available platforms, many technical issues and limitations were encountered.

Office 365 is an enterprise-grade cloud platform that promises reliability. However, we encountered several instances where the cloud service was degraded, sometimes for several hours at a time. This resulted in confusion and frustration when the tools did not work as expected, with cryptic error messages that did not clearly identify the problem. This happened more than once during the scheduled lab time.

The Office 365 environment is unnecessarily confusing and non-intuitive. This seems to be a trend with modern software. The problem is compounded by a lack of clear user documentation or guides. It was necessary to provide separate step-by-step documentation for student to follow.

SharePoint sites lack clear navigation tools, so it is easy to get lost. There is no standard navigation link to go to the top level, to go to the parent site from a subsite, or to go back to the previous page. These links need to be added as part of the site design.

It is possible to "follow" sites, which are then displayed as panels on the SharePoint page. However, the overall structure of a site collection is not visible. If a user follows many sites, it is difficult to navigate to a particular one. The only way to find sites is to use the "search" function, which was found to be unreliable.

OneNote provides no commenting tools, so users must find work-arounds to comment on content. Apparently Microsoft is aware of user demand for commenting, and hopefully this will be addressed in future releases.

Word provides no effective tool to review the history of a document, with a timeline of contributions by different authors. The "track changes" feature is not really suitable for this purpose.

7. IMPLEMENTATION AND TESTING

Western University has an institutional license for Office 365, but SharePoint functionality has not been enabled by the site administrators and so is not available to users. The Western Faculty of Engineering has a separate Office 365 license that provides full functionality. Access is limited to Western engineering faculty, staff and students, and a separate Office 365 login is required. The Western Engineering license was used for this project.

By default, all Office 365 users are able to create SharePoint sites within their personal spaces, and share the sites with other users. Users have full administrative control over their own SharePoint sites, so no technical support is required. Setting up and configuring SharePoint is fairly straightforward, though many aspects are counter-intuitive and poorly documented. It is possible to create a team site in a few minutes, and sites can be created for an entire course in a couple of hours. In this case, the author created 34 sites with minimal outside technical support. Much of the implementation involved repeating a series of about a dozen setup steps for each site, using a web interface.

A prototype shared workspace was implemented as a SharePoint team site with a shared OneNote team notebook, a SharePoint discussion forum, a SharePoint document library, and SharePoint project management tools including a task list and calendar. The affordances and capabilities of the tools were tested for a variety of typical collaborative scenarios, and documentation was prepared with detailed instructions, guidelines, and recommended practices. Limitations and work-arounds were noted and documented.

8. DEPLOYMENT IN A DESIGN COURSE

The tools were then deployed for a 2nd-year mechanical engineering design course at Western University in the Fall 2016 academic term. There were 134 students working in 34 teams of 3-4 students. The teams each completed a product design project that lasted the full term. In previous years, students were required to maintain a personal design notebook, which was evaluated for a small portion of the course grade. In lieu of a paper notebook, students were required to maintain a digital design notebook for their course project. They were also encouraged to make use of the other SharePoint facilities, particularly the task management tools for project scheduling. A small mark was allocated to the frequency and quality of contributions to the shared notebook and SharePoint team site, so most students participated and used the tools.

Student teams were instructed to use the shared OneNote team notebook and SharePoint team site to clearly document each phase of the design process over the

duration of the course. The phases included: specification development and planning; conceptual design; and detailed design.

The specification development and planning phase documents the problem statement, design specifications, and project plan. Tools and methodologies used include Quality Function Deployment (QFD), Gantt Chart, and Critical Path Method (CPM).

The conceptual design phase documents concept generation and selection. Several alternative concepts should be documented, and the rationale and criteria for selecting the best concept should be clearly justified. Tools and methods used in this phase include functional decomposition, morphological analysis, sketches, feasibility analysis, technology readiness assessment, go/no-go screening and decision matrices.

The detail design phase includes selection of components, CAD modelling, and design evaluation. Students were encouraged to include annotated screen captures of CAD models in the team notebook. It is important to note that SharePoint has no facilities for managing shared CAD files. This is an important shortcoming for many engineering design projects.

Students were provided with tips and guidelines for effective use of their team notebooks. In particular, they were encouraged to include freehand sketches and calculations, screenshots, photos, web clippings, etc. in their OneNote notebook. They were also encouraged to use the group editing tools in Word, Excel and PowerPoint to collaborate on group documents including design reports, progress reports and presentations.

9. EVALUATION

The criteria listed below were used to evaluate the team design notebooks. These criteria were shared with the students in advance. A simple rubric was used to assess level of achievement in each of these criteria.

9.1 Notebook content

Notebook must be well organized, and it should be easy to find information documenting all phases of the project. The notebook and other SharePoint resources should fully document all phases of the project.

In addition to the final documentation, the notebook should contain rough notes, rough calculations, comments and discussions, informal thoughts and reflections, preliminary sketches, etc. This content does not need to be "cleaned up", as the OneNote notebook serves the same purpose as a traditional design notebook or journal for rough notes.

All tasks, task schedules, timelines and progress should be clearly documented. The SharePoint task tools are recommended, but equivalent alternatives may be used.

9.2 Individual contributions

All members of the team are expected to make regular contributions to the shared notebook and other SharePoint resources. The contributions should be equally distributed over time, and among team members. All contributions are automatically labelled by username and timestamp. If only one or two students are responsible for most or all of the contributions, the contributions of the other members must be clearly identified and justified.

9.3 Tracking Contributions

Contributions were tracked and assessed using the affordances available in Office 365.

SharePoint "alerts" were set for the different components of each team site. An alert sends an email notification every time a change is made to the content of a site. The changes are indicated along with a username and timestamp. These email alerts gave an idea of the frequency of contributions by different team members.

Document libraries show the username and time when a document was last edited. Document libraries also provide version histories, showing changes made over time. This provides a snapshot of the distribution of changes over time, with usernames and timestamps.

Detailed contributions to a Word document can be tracked using the Word review tools, particularly "Track Changes" and "Show Comments". However, it is not possible to search or filter changes based on username.

Contributions to the SharePoint team site forum were easily tracked. However, few students used the team forums.

OneNote provides several basic tracking tools in the History toolbar. Edits to a notebook can be listed and sorted by date or by author. Contributions are also indicated on the notebook page with user initials.

10. OBSERVATIONS

After training, students had no significant difficulties learning and using the tools and little technical support was required. However, most students did not make full use of the tool capabilities. Many students were observed to keep notes in personal paper notebooks, instead of or in addition to the shared OneNote notebook. Few students used freehand input, but many discovered the facilities for easily capturing and incorporating images of freehand sketches using their smartphones. In these cases, students would take a picture of a notebook page, and add it to the digital notebook. Some teams used shared Word, PowerPoint and Excel documents in the document library instead of the OneNote notebook.

There was relatively little evidence of higher-level collaborative activities, and most teams used the notebook and document library as a reporting tool rather than as a

collaboration tool. It was also noted that most of the notebook entries occurred during the lab time, so most students were not using the tools outside of class time. Collaborative activities were observed to occur during face-to-face meetings during the labs, and many of these activities were not captured or recorded in the notebook.

11. CONCLUSIONS

Collaborative digital design notebooks have many advantages over traditional notebooks. In particular, they can support collaborative knowledge building. Current technology provides most of the required functionality, and implementation of an effective collaborative digital design notebook is technically straightforward using widely available and affordable tools. The collaborative digital design notebook implementation using SharePoint and OneNote satisfied most but not all of the identified requirements. The implementation can be scaled to large design classes, and students can use the tools with minimal training or technical support.

However, students lack skills and experience in collaboration, and do not naturally adopt effective collaborative practices. In order to be successful, we need to teach collaboration skills and practices as well as providing tools and environments that support collaboration.

12. ACKNOWLEDGEMENTS

The author wishes to thank Prof. Paul Kurowski for offering the opportunity to test and evaluate the collaborative design notebook in his design class in the mechanical engineering program at Western University.

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