Advances in Engineering Education

SPRING 2018

Potential of the CogEx Software Platform to Replace Logbooks in Capstone Design Projects

DAVID FOLEY

FRANÇOIS CHARRON

AND

JEAN-SÉBASTIEN PLANTE
Université de Sherbrooke
Québec, Canada

ABSTRACT

Recent technologies are offering the power to share and grow knowledge and ideas in unprecedented ways. The CogEx software platform was developed to take advantage of the digital world with innovative ideas to support designers work in both industrial and academic contexts.

This paper presents a qualitative study on the usage of CogEx during capstone design projects in mechanical engineering. It explores its potential to eventually supersede a paper logbook. This study combines three pilot projects where 15 undergraduate students used CogEx for one semester and discussed their experience in a final interview. The focus is limited to individual usage in this study.

Results support that the platform has a good potential for engineering design education by replacing the paper logbook. The "extended concept mapping" structure was efficient to organize design work, and although the "concept-knowledge" separation needs refinement, it has good potential in building designer knowledge base.

Key words: Design practice, Capstone projects, Undergraduate, Qualitative, Learning technology

INTRODUCTION

Most undergraduate mechanical engineering programs in Canada use a capstone design project to teach and assess many of the competencies required by the program, notably design skills (Hurst and Nespoli 2015; Dym et al. 2005). The program at Université de Sherbrooke exploits a major capstone design project that spans over 3 semesters and brings teams of students from project definition to fabrication and testing of a prototype. Experienced designers follow every team weekly and give one-to-one feedback and evaluation twice per semester. Students are taught to record all their work in a paper logbook, and this represents the main tool to support the whole activity. The method has proved its efficiency in the last twenty-five years at Université de Sherbrooke. Yet, technology has greatly evolved and much of the design work and information sources are now from the digital world. Paper is not appropriate to organize and manage the CAD files, web bookmarks, and all the collaboration exchanges often made on social network platforms. Many students are asking to use a digital logbook and teams are building their own amalgam of software (*Microsoft Word, One-Note, Teamwork, Facebook*, etc.). The heterogeneous tools between teams make it harder for the teacher to navigate and understand the whole of the design data, and it compromises the sustainability of design information for future use. In response to this need and in view of the opportunities that the digital world offers to support design in the industrial and academic contexts, a software platform called *CogEx* was developed to support work organization, learning and collaboration. *CogEx* is designed with breakthrough innovation in mind and thus suggests ideas that need to be tested. *CogEx* needs to be validated and explored with pilot studies. Capstone design projects of undergraduate engineering students has offered a rich experience for such research.

BACKGROUND OF THE STUDY

Decades ago researchers have worked to transition from the paper logbook to digital counterparts. The chemical and pharmaceutical industries have been at the forefront of the development and usage of such software. The result is a family of software called Electronic Lab Notebook (ELN) used to store, retrieve and share laboratory records. For consistency, persistence and legal concerns, commercial ELN tend to force some structure and may lack fluidity and flexibility for design tasks (Oleksik, Milic-Frayling, and Jones 2014). ELNs are not designed to organize the breadth of design activities and are often used in conjunction with what Oleksik calls a “master notebook”, to track the various facets of a project (*ibid.*). Generic note-taking software such as Microsoft *OneNote* (Eblen-Zayas 2015) and *Evernote* (Walsh and Cho 2012) are used by some institutions as a more flexible and readily available alternative when intellectual property is not a stringent requirement.

Tabard, Mackay, and Eastmond (2008) have worked on a hybrid solution between paper and digital logbook. They developed *Prism*, a paper notebook that uses *Anoto* technology to digitized and augment the content. It contains digital text and images, linking to documents and web resources, and sharing of notebook entries. The author demonstrated that *Prism* can be used as a “master notebook”, but that people nevertheless preferred paper. They argue that paper helps researchers maintain a discipline in recording their work and that the externalization of memory on paper helped filters and organize information.

A trend of technology that deserves mention is the web-based collaborative project management platforms such as *Teamwork*, *Wrike*, *Huddle* and *Asana*, just to name a few. These technologies are designed to improve team work and project management. All work that lives in digital documents are managed by the system and can be commented by collaborators. There is little literature on these commercial products, but they are rapidly growing in popularity. These platforms can serve as master notebook to organize everything. They perform well for task management and collaboration, but they do not offer an appropriate space to create and solve. For that aspect, they rely on documents created with other software.

Description of CogEx Tools

The *CogEx* platform was developed by building a conceptual framework that describes the design activity and then by identifying new ways to support designers. This section offers a summary of the theoretical underpinnings of *CogEx* needed to understand the current study, and the following short video in Figure 1 presents the software in an engineering education context.

Conceptual Framework

The conceptual framework of the design activity is based on Vygotsky and Leontiev activity theory (Vygotsky 1978) which describes an activity as the interaction of a person with an object inside a community. Figure 2 shows the framework adapted to the current study. The designer

Figure 1. Video presentation of CogEx.

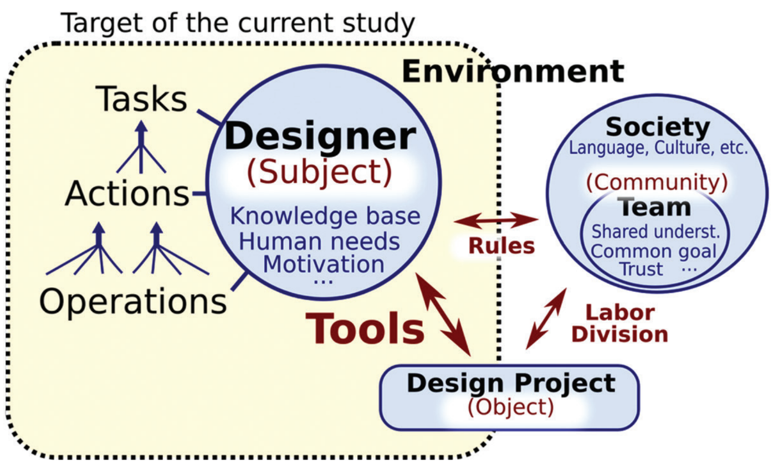


Figure 2. Evaluation framework of design activity in the CogEx.

interacts with the design project with tools and evolves inside a team and society by following rules. The highlighted area illustrates that the focus of this study is on the individual designer. The conceptual framework is used through the study to build the questionnaire and to identify themes for the thematic analysis of the interviews.

The model distinguishes three hierarchical levels of actions. The most basic level contains *operations* that are performed automatically, such as understanding visual representation, reading, writing, drawing lines in a sketch, making sense of information or memorizing. They are the building blocks of *actions*, which are conscious and goal driven. This includes solving a problem, building a record of design work, creating new concepts and analyzing them. Actions are themselves building blocks of more or less sequential tasks found in design. For this research, they are limited to project planning, conceptual design and embodiment design.

Extended Concept Map

Extended concept map is a graphical representation developed to organize all the data. It is inspired by concept map (Novak and Canas 2008) but makes every concept box a possible container for recursively nesting other extended concept maps. Figure 3 shows how a student of one pilot study organized his work in this structure. The project is done in French, so translation is provided in parentheses. Figure 3 (a) shows that the participant has used separate concept boxes to categorize the important parts of his design project (Rotor System, Control Test Bench, Range of Operation, Administration). If the concept "Range of Operation" is zoomed in, it leads to display (b), where all the details are organized in a concept map to show how the student has used analytical

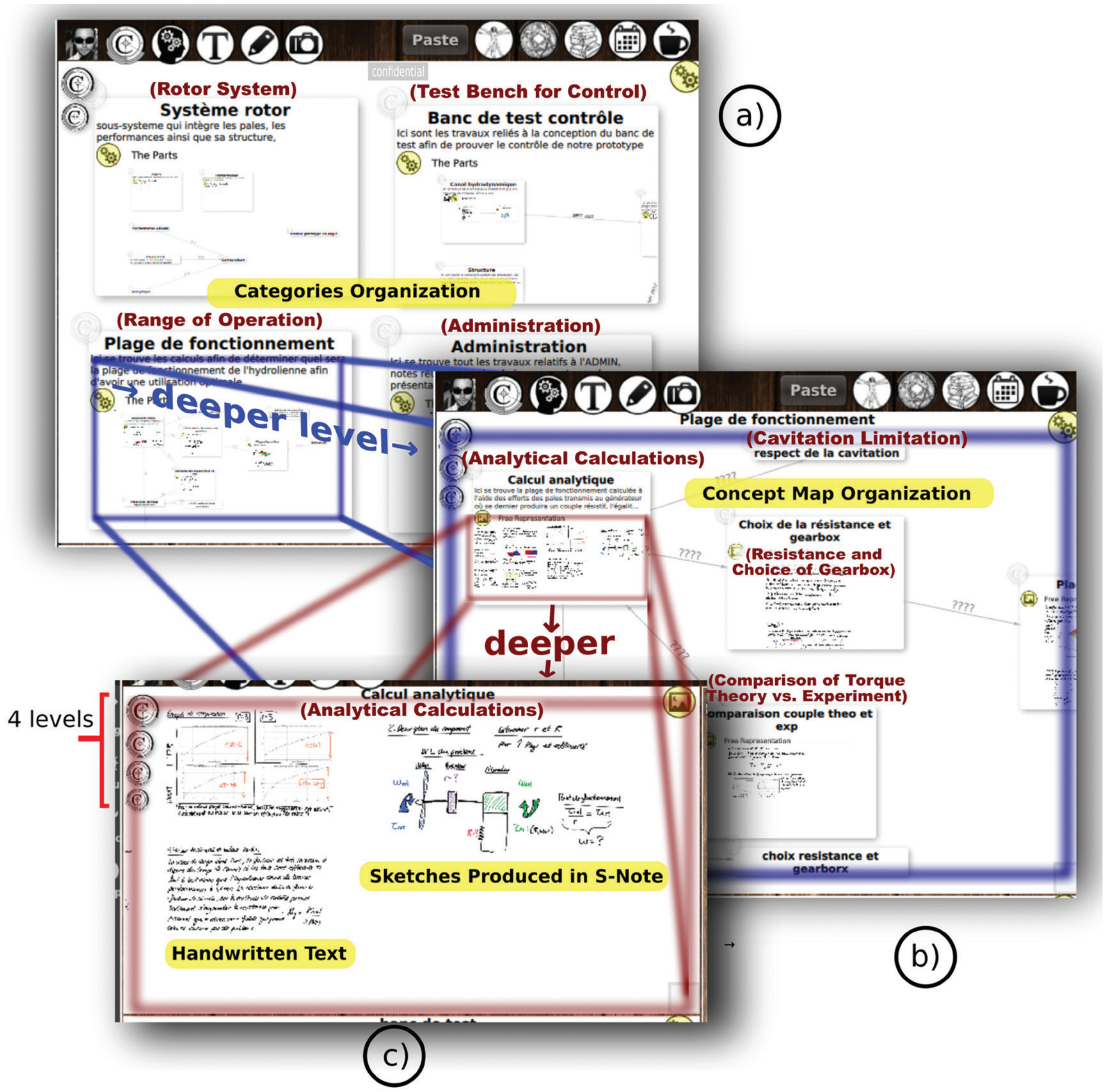


Figure 3. Organization in the extended concept map.

and experimental data to decide on the range of operation. Further navigation by zooming on the concept "Analytical Calculation" shows the details of his analysis work, shown in (c). The structure allows organization and navigation through a huge amount of information. It holds resemblance to the zooming capabilities of *Google Maps*. Extended concept mapping is inspired by how experts organize knowledge in functional chunks (Feltovich, Prietula, and Ericsson 2006) and by the important place given to abstraction and contraction in the conceptual blending theory (Fauconnier and Turner 1998). The extended concept map should help designers in two ways: 1) the proximity with

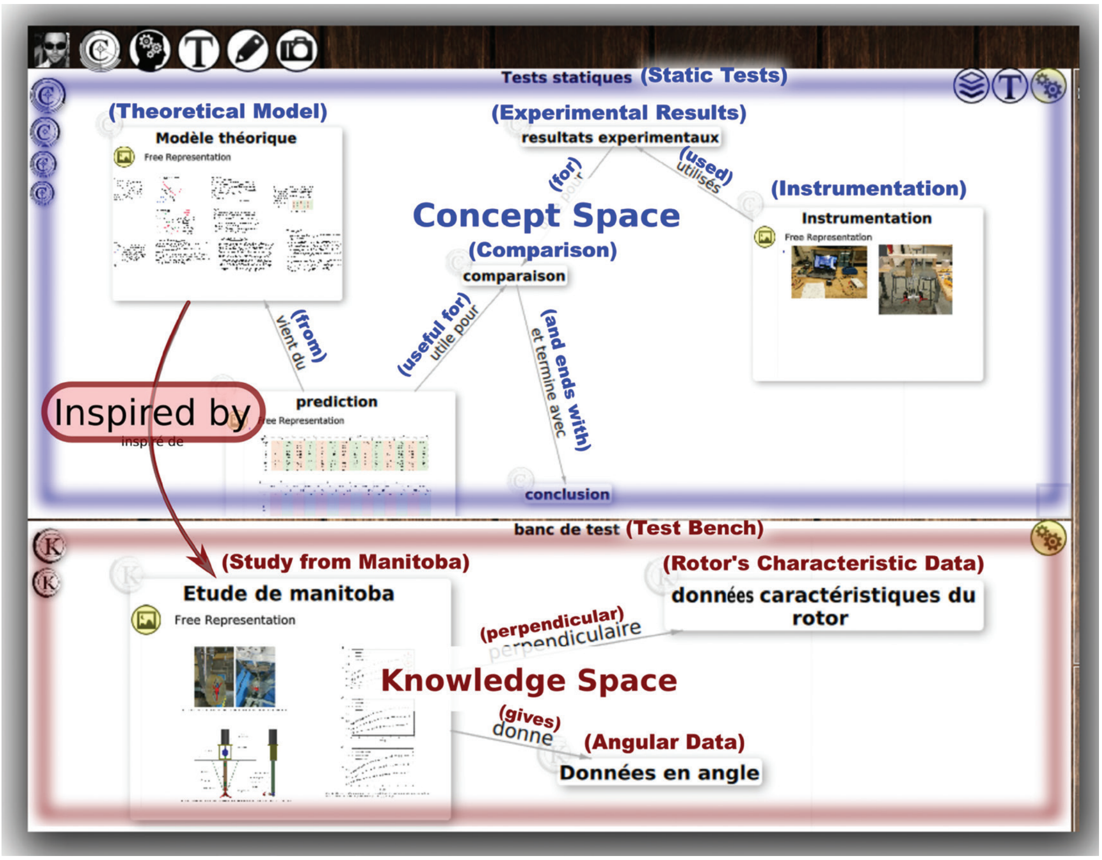


Figure 4. Concept and knowledge interrelated spaces.

cognitive organization makes the structure intuitive and efficient for designing; 2) the multi-level structure affords organization and interconnection of life-long amount of projects and knowledge, potentially improving learning and problem solving.

Concept Knowledge Spaces

Concept-Knowledge spaces (C-K spaces) is how the workspace is split vertically in two as shown in figure 4. The concept space at the top is where all data and elaboration of the particular project is organized. The knowledge space at the bottom is where the user builds and grows his knowledge base while he works on a project or when he is actively learning. The figure shows how one student organized his knowledge of rotors test bench in the knowledge space and how he relates to this knowledge in his concept space where he develops a theoretical model of the rotor. The knowledge base is the same ever-evolving extended concept map that grows across all projects and that should favor knowledge integration and reuse. The process of designing is a back and forth movement between the C-K spaces, so knowledge and concepts are interrelated. This organization has the potential to improve learning by connecting knowledge with real life project (Sanson-Fisher and Lynagh 2005). The C-K spaces is a loose application of the C-K theory (Hatchuel and Weil 2002) and should offer a good base to capture design rationale.

Integrated Data Management

Integrated data management is a challenge pursued by many software products. Our programming resources being limited, the work was mostly focused on managing text, pictures (from files or captured by a webcam), external files (Office files, CAD, pdf, etc.), and tasks in a to-do list. We tried to include a stylus input with good sketching and handwriting, but it did not work properly for the pilot studies. Even if the implementation was incomplete, it did not stop discussions on the value of having a central place to manage everything.

Capstone Design Projects at Université de Sherbrooke

The capstone project at Université de Sherbrooke is an important part of the curriculum and ends with a complete prototype. Students can define the project by themselves or they can work on a project offered and financed by industry. Beyond design solutions, the project includes aspects such as finance, negotiation with clients and project planning. The capstone project spans three design courses that correspond to design phases: 1) need analysis and conceptual design, 2) detailed design, 3) fabrication and testing. Teams are typically between five and twelve students, depending on the complexity and size of the project. Teammates work together for the final two years of the program to design, build and validate their solution. Teams present their prototype to the public in the "Mégagénial" exposition. The projects of the last edition can be seen at http://www.expo-megageniale.com/.

Purpose and Approach

A pragmatic epistemological perspective is taken to study how students understand *CogEx,* how they adopt it to satisfy their logbook needs and how it can be improved. The main goal of the study is to explore the potential of *CogEx* to replace the paper logbook of engineering design students to support capstone design projects. A qualitative research strategy is chosen to increase the overall understanding of how students interpret and use the various features of *CogEx* to support their design activity. A complementary goal of the study is to improve the platform and incremental changes were applied during the study in response to comments from participants. The final results also orient bigger future improvements. Three pilot studies were conducted from 2014 to 2016 with 15 undergraduate students during the conceptual or detailed design phases of their capstone design project. They were asked to use *CogEx* instead of the otherwise mandatory paper logbook to organize their design work for the full semester. The principal method of data collection is a final interview with open-ended questions structured around the various parts of the conceptual framework presented earlier. Besides, the researcher used informal discussions with participants all along the study and kept a journal of observations. The study is limited to the individual aspects of the platform with a limited number of participants. No full project team was engaged in any of the pilot studies. The current work allows adaptation of the platform to higher standards and will make it possible to enroll full teams to study the collaborative functionalities.

Results

The results of the pilot studies confirm the potential of the solutions proposed in *CogEx*. This first assessment confirms that the platform is a valuable tool to organize design work and support design education. The study helped identify improvements that pave the way towards a design logbook more attractive and efficient than the paper logbook, opening the door to a more involved study on the development of the design competency of students including the collaborative aspects of *CogEx*.

This paper first presents the methodology of the study and the conceptual framework that is the foundation of the platform. It then presents results of the interviews organized from a thematic analysis. Finally, it discusses the meaning and implications of the results for future implementation of *CogEx* in the undergraduate engineering program at Université de Sherbrooke.

METHODOLOGY

Participants

The participants engaged voluntarily and the study follows a protocol that has been approved by the ethics committee of Université de Sherbrooke. Every participant signed a consent form. The confidentiality of the students is preserved by changing their names to a letter, and the participation in the study had no consequence on the evaluation for the design course. The criteria for participant selection are simple. They must follow the design course and they must be willing to use *CogEx*. There were also two studies requiring an Android tablet. Participants could either buy a tablet or else we loaned them one for the period of the study so that money investment was not an issue. Each pilot study proceeded with new participants.

The pragmatic and exploratory nature of the research pushed in favor of small groups of participants to offer better support and to implement incremental changes faster. Yet, the groups were

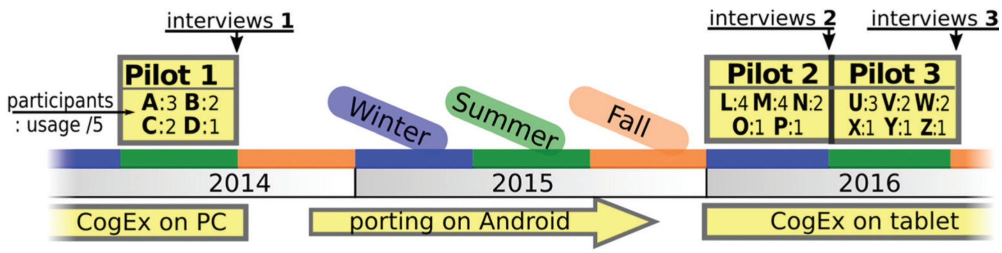


Figure 5. Time-line of the study.

big enough to offer good exploration. The three pilot studies respectively included 4, 5 and 6 participants. Figure 5 shows the time-line of the pilot studies and every letter and number in each pilot study represents a participant and the rating of their involvement in using *CogEx*. The participation level is from 1 to 5, where 1 is just trying out the platform, and 5 is using the platform as a full logbook replacement. The rating is given by the researcher based on the interviews, on the researcher's journal of observations, and on the amount of content in the participant's *CogEx* workspace. In every case, all participants used *CogEx* sufficiently to discuss all themes of the questionnaire. The most involved users supplied deeper insights.

Time-line

Figure 5 illustrates the time-line of the studies. Pilot studies 1 and 3 were conducted during the conceptual design phase of the capstone project, and pilot study 2 was done during the detailed design phase. A major change occurred after the pilot study 1, which used a personal computer (PC) to run the software. In this first study, hand sketches were captured with the computer camera and placed in the digital logbook. The principal conclusion of this first study was that the lack of direct sketching capabilities and the low portability of the laptop compared to paper logbook led users to do their work in a disorganized paper logbook, and subsequently organize part of the information in the digital logbook. The platform was used as an organizer, but the goal of the current platform is to act as an organized workspace that directly supports the designer in actions. It was decided to build the software to work also on Android tablets with pen capability to allow direct input of handwriting. The two other pilot studies were conducted on Samsung galaxy note tablets with a redesigned interface, but the fundamental concepts of the overall solution were kept untouched.

Data Collection

Since the start of the capstone projects in the curriculum, students are required to keep track of their work in a paper logbook, which is used by the teacher for evaluation and to give feedback. The pilot studies asked students to replace the paper logbook by *CogEx* for a full semester. One of the researchers gave a one-hour training session at the start of the semester to show how to use *CogEx*. The selection process and various challenges at the beginning of the pilot studies consistently delayed usage of the platform by 2 weeks after semester's start. Participants often used a temporary notebook in the meantime. One researcher was available during the study to answer questions and solve any problems with the platform. The interactions with the researcher were done by phone, in optional weekly meetings, and with a discussion forum where participants were encouraged to post their difficulties, wishes and ideas. Some of these comments were integrated through software updates during the study. Observations from the discussions were kept in a journal during the study. In the last week of the semester, the researcher interviewed every candidate with a questionnaire of six open questions that targeted the themes highlighted in our conceptual framework. The interviewer encouraged participants to share any other thoughts about the platform. He specifically asked to discuss the usability and appreciation of: 1) the extended concept-map organization, 2) the division of work in concept and knowledge spaces, and 3) the support of all design tasks and design information. Moreover, the interviewer asked the participants what would contribute the most to improvement: 4) in efficiency of *CogEx* during design, and 5) in raising the desire to use the platform. The students were encouraged to discuss anything related to design, including ways of working, bugs encountered, wishes and other software that performed better for some tasks. Interviews were approximately one hour long and were recorded for further analysis.

Data Analysis

Interviews were transcribed by the researcher and a research assistant. The transcriptions and the researcher's journal were then analyzed to identify and code important themes. The initial list of themes comes from the conceptual framework and the features of *CogEx* presented in section 1.1.1 above. Other themes emerged as the coding proceeded. After two coding iterations, every phrase was organized under the theme(s) that they express. The themes were grouped into categories and further classified in one of the big parts of the conceptual framework: operation, action or task levels, or community. The result and the discussion sections are presented with this structure. Engineering data needs are presented in a separate section.

Strength and Weakness of the Study

The researcher is also the developer of the software. An advantage, in line with the pragmatic view of the research, is that it brings a direct conversation between the software developer and the users, thus building a good understanding of the needs and perceptions. A disadvantage is that participants may have friendliness bias, since their comments directly criticize the work of the researcher. To avoid this bias, the researcher dug deeper for answers during the interviews and he explained to participants that good critics are beneficial for the study.

A strength of the study is the prolonged period of study with three different groups. The changes in the platform after the first pilot study are reflected in the comments and on how the platform was used. Interestingly, most other themes are present and consistent in all three groups.

All participants in the study are undergraduate students in mechanical engineering and novice designers. It is likely that the platform applies to other fields and to higher levels of expertise, but transferability is not tested in any way. For example, the platform seems fit for medical education where a logbook provides an opportunity to get feedback and help self-reflection (Gouda 2016). However, other pilot project will be necessary to study *CogEx* in these contexts.

Finally, the voluntary basis for participating in the pilot study may bias towards people that appreciate working with software technologies. This is judged acceptable for the current stage of development of the platform and for the goals of our study.

RESULTS

The results of thematic analysis are presented here through a set of representative excerpts from the interviews and images showing the *CogEx* workspace of some participants. The interviews are in French and are translated for this presentation.

Human Operation Level

Visual Presentation and Navigation

Figure 3 (a) and (b), and the video of figure 1 show the interface with its simple toolbar at the top. Five generic creation tools are bundled on the left, and five more specific icons are bundled on the left for contacts, standard properties, references, tasks and comments. Buttons react to three actions that are as consistent as possible across them: click is selection, long-press opens details or configurations, drag and drop is an intuitive way to create new objects in the interface where the user wants them. Moving objects and creating links are also made by drag and drop actions. The interface was generally appreciated and no issues have been raised about the general presentation and about how to interact with it.

The navigation in the data happens by moving and zooming into the extended concept map. Participant **L** judged that this “infinite zoom” functionality is one of the best features of *CogEx*. Although generally appreciated, the zooming interface can be improved as explained by **X** when zoomed out concepts become very small. “Sometimes it is small. Is it possible to keep things bigger? I would make buttons disappear when they are too far." He goes on explaining that interaction should be restricted to concepts that are big enough for the fingers. The reader can refer to figure 3 for an example showing the size of zoomed out concepts.

The interactions to navigate in the data were judged acceptable for some, and perfectly good for others, as expressed by **B**, "There is no need for more navigation options. It works very well like that." For most participants, however, the order of the navigation list did not feel intuitive and needs to be reversed.

Input Devices

The four ways participants could produce their data are by handwriting with the stylus, keyboard input, image capture and importing files. The first pilot study was on a PC and handwriting was not available directly. It impeded using the platform to its full potential. When participants **C** and **D** of the first pilot study were asked what were the most difficult tasks with *CogEx*, both answered that sketches and equations, which could use handwriting, were problematic.

The next two pilot studies have been conducted on a tablet with a stylus to solve the handwriting issue but the sketching was not good enough and did not resolve the issue. As **L** stated it, "sketch (from *CogEx*), I did not get anywhere with it". Most participants, including **L**, used the platform to organize work they produced on another electronic notebook application, such as *S-Note* or *One-Note*. The integration of a good sketcher is likely to remove this duplication of work. **M** explained how he used *CogEx* in combination with *S-Note*:

> *"At the end of the day, or after few days, I was taking what I had done in S-Note and I would transfer it in CogEx.* Sometimes in the morning if I had an idea of what needs to happen in the week, I would prepare, let's say, concepts at the organization level in CogEx to integrate faster my things from S-Note."

The usage of tablets highlighted an issue for entering text. The virtual keyboard on a tablet takes up half the screen and is not efficient compared to a hardware keyboard. Participants tended to resort to handwritten notes on the tablet. As **W** said, "the default of the tablet is the keyboard" and he went on suggesting using an external keyboard with the tablet. The tablet is not fit for entering long text as **U** expressed it: "we can all agree that I will not write down 30 pages of design report on my tablet! I will go on the computer for that."

The first pilot study on PCs revealed that portability was important. For example, **C** reported that "I didn't always have my computer, so half of the time I would write things on paper and then transcribe it." The tablet does seem to solve the issue of portability, as no participant reported this problem in the following two studies with tablets. Still, the tablet cannot be the unique work device because some tasks need a workstation. **W** explained that "for the project, we need to build CAD, we need to build models. That cannot really be done on a tablet. It needs a computer geared for design work." Some participants simply prefer the PC to browse the web or to work in general.

It was mentioned that ideas and solutions often arise anywhere outside the design activity. A fast memo is often all you need to keep your idea safe. This requirement is not fulfilled by the application because login is a bit too long and you need some steps to place new ideas correctly. "If you want to take a quick note, it is not as fast as a (paper) logbook that you just open at the right page and Bam! You take your note" (**V**). Moreover, it was suggested that a stripped-down mobile phone application would be a nice addition to the platform. **W** described it this way:

> "Sometimes I do a session where I sit down and think about the project, but it's not how I get most of my ideas. It was while doing something else. […] I don't always have my logbook, so if I have my tablet or even my cellphone, then I can note my idea."

Organization

The platform presents various tools to organize designer's work. The extended concept map is the principal basis for organizing everything. It is mostly useful to retrieve previous work. The chronological organization can also be useful to find information (**X**, **L**), but only when you remember what was recently done. Figure 3 used above to illustrate the extended concept map shows how participant **L** used it to organize his work. His work is generally organized in three levels, where the highest level is the big parts or the facets of his project (figure 3-a), the second level contains more details and sometimes the logic to solve the problem (figure 3-b), and the third or fourth level holds the details of analysis or concepts, often with more handwriting, images and links to files (figure 3-c).

The functional organization offered by the extended concept map was seen as more powerful to organize long-term work. Participant **X** reported that with the paper's chronological organization, he keeps everything in his head, which is not the case with the way *CogEx* allows him to organize his information by subjects (or concept). Most of the time, he searches for a subject, not a date.

Most participants used almost exclusively placement of various boxes in space with sub-boxes in them with little or no graphical links between boxes. **U** described making boxes and sub-boxes as making categories and that "it is somewhat the way I work in my life, and it helps me a lot to navigate because it is just logical." Figure 6 shows an example of workspace which mostly used nesting. Even if most participants did not use linking phrases extensively, they generally found them interesting. For **M**, links are one of the very useful functionality of the tool. He explained that "you can write the relation between two concepts, it can be just a keyword to say how you move from

Figure 6. Organization of work mostly with nesting.

one concept to the other, or it can be about the process." Figure 4 shows how linking phrases are exploited in both concept and knowledge spaces.

Participants recognized that the extended concept map offers a good overview of the work. The levels of abstraction have a role to play and **V** argued that "the concept of embedded boxes makes a lot of sense, because if you want to see an overview of your project, then you just go see your big (higher level) boxes." The concept mapping part of the extended concept mapping also contributes to offering overview as **U** said it, "concept map is something I like a lot to get a big picture of the problem, of my system, no matter what it is."

Most participants had not worked with concept maps before and there was a learning curve to go through. It can be challenging to start the extended concept map, "to build the general file" as stated by **V** who reported having changed three to four times his general structure at the beginning. Some participants also found that it sometimes took quite some time to organize the information while working.

Some ways of organizing the information can lead to deep nesting that increases complexity and makes navigation harder. **X** remarked that "when you have to go down six boxes, when you go too deep, you can get lost in your ideas." However, the interviewer asked users if they ended up creating too deep a hierarchy and participants generally learned to balance their structure of organization to avoid this issue. "I organized it not to go too deep (not too many levels of nesting). I think that otherwise there are ways to reorganize things so you don't make it too deep" (**U**).

Designer actions level

Concept and Knowledge Interconnected Spaces

The C-K space division is mostly considered to be intuitive and useful to organize work. Participant **W** expressed that he finds "the concept-knowledge method is much more intuitive than what I used before. (It is) efficient and useful. I started to do that (splitting C-K) in all my other work." **V** explained how it helps to reuse and expend knowledge; “if I learn new fabrication techniques, or whatever, I put this in my knowledge categories, because it allows me to really expand my vision and my knowledge.”

Participant **X** noted, however, that he found the division disruptive, because “since you split your information in two, you always have to search in two different places.” It was highlighted that switching between one space and the other can be distracting. This also applies for switching between spaces for different concepts.

Most participants only used the concept space. The main reasons stated for not using the knowledge space are the following:

1. There is only a long-term benefit that was beyond their project, as expressed by **V,** “in the short-term I only would have my project there […] but I think it can be pertinent if you use it on long-term.”
2. It imparts some cognitive load to decide what goes in knowledge space. “(For knowledge) I try to think too much of what I will use again someday. I think long-term and I don’t know where to put my things in the short-term” (**U**).
3. The knowledge is already available somewhere else. **M** explained, “I could see the usefulness writing it (in knowledge space) but since I already had it in my book I was going to my notes. It was a one shot deal.”

X suggested that starting from some existing knowledge base would make the knowledge space more interesting and useful, “it takes a good base so that you finally come back use knowledge space.”

Maintaining a Logbook

Maintaining a proper logbook is a habit that is not natural for many students and it takes some effort. In this vein, **D** suggested that “we shouldn’t get the impression that organizing things in the software takes more effort than paper […] this effort will take priority over the future advantages (of using *CogEx*).” For participant **V**, the barrier for using *CogEx* was earlier in the process, “The main reason why I did not use it more is really just a lack of time to learn new software in the semester, because I would really have liked to use it more.” The need for a digital replacement of the paper logbook is still generally recognized by participants and is expressed in statements such as when **U** said, “I think that everybody agrees to say that paper logbook is outdated, and a lot of the disadvantages of paper logbook are solved in your software (*CogEx*).”

Design tasks level

Project Planning Task

Task management is frequently, if not the most mentioned tasks during the project. When **Z** was asked what type of information and what tasks are the most important to write in his logbook, he

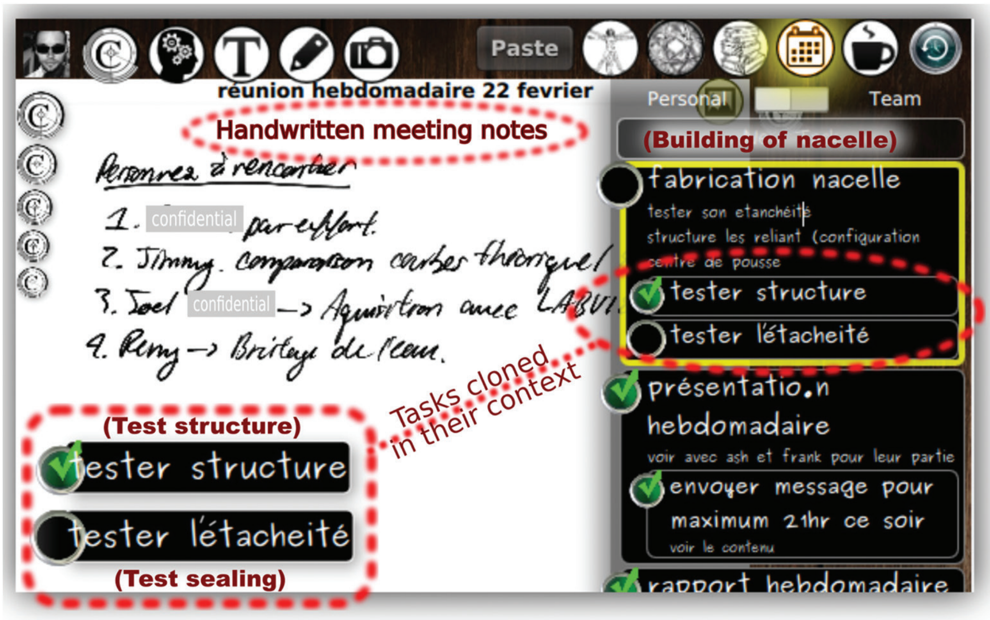


Figure 7. Tasks and notes from a meeting.

answered that "(it is) tasks to be done. It is important to have a space to keep the planning. What and when things must be handed in, because often, doing is not the hard part, but doing it in time!" For the planning task, *CogEx* offered a task list as shown on the right in figure 7. The last added task is added on top. This automatic order could not be changed in the version used for the study. Figure 7 also shows how tasks can be cloned in the workspace to make them visible where they are most pertinent. Most participants used external software, such as *Teamwork* for their task management. They liked the collaborative aspect of such external tools because they could share and follow tasks of the whole team. Participant **X** who has used *Teamwork*, explained that:

> "The principal functions they used from Teamwork were assignment of tasks to different people, assignment of the same task to many people, and sometime, assignment of a responsible for a task that many must do, like giving back this sheet, but everybody must sign it."

Conceptual and Embodiment Design Task

The logbook is designed to first support the conceptual and embodiment phases of design. This support occurs from the properties of the extended concept map by tracing the evolution of the

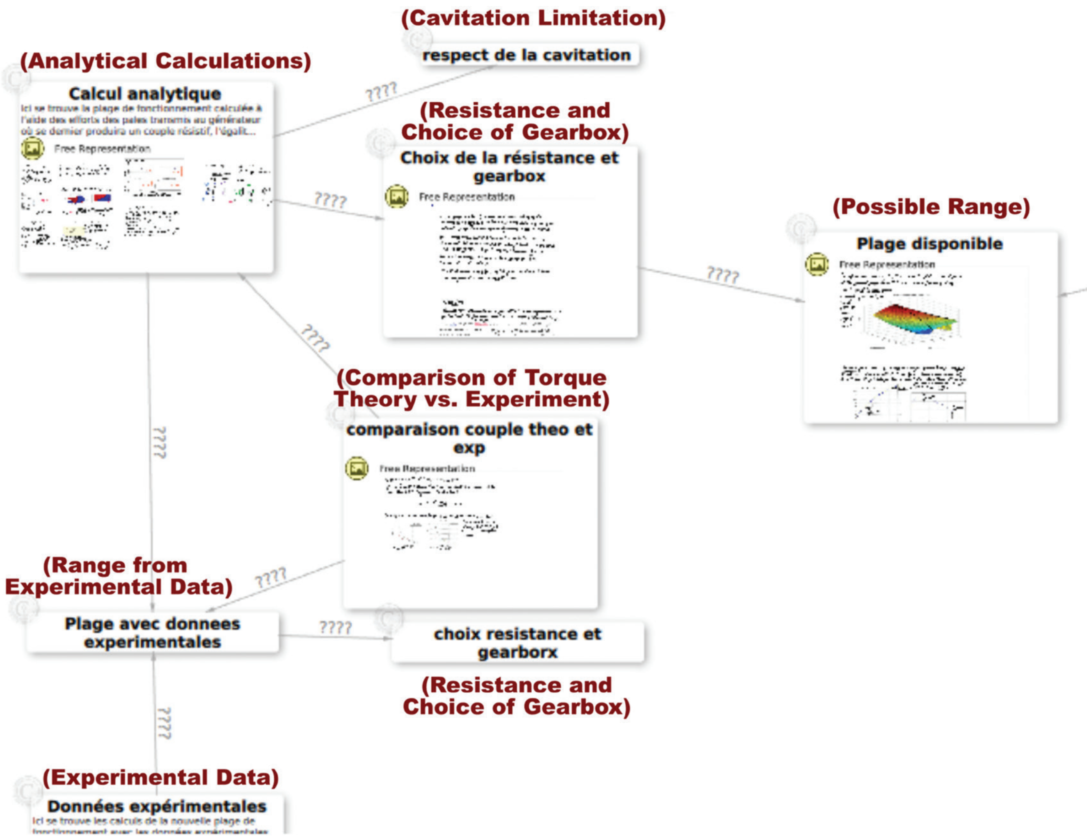


Figure 8. Representation of design rationale.

design solutions and by giving the ability to evolve the work around any piece of existing data. Talking about the evaluation of concepts and the generation of solutions, **W** pointed out that "with CogEx, with its way to schematize, it is really good." Similarly, **U** described that "what is really a must, it can be called the evolution of concepts, it is the fact that you can always change anything and you can always add things right where they belong, where you already started something." When participant **L** participated in the study, he was in the embodiment design phase. Figure 8 shows his work and how he linked his concepts to trace his design rationale. Although he has not used any linking phrase, his workspace representation shows that he used analytical calculations to choose his gearbox and to decide on the working range of his prototype.

Participant **L** explained how he used *CogEx* to support divergent thinking. In his interview, he was showing a central box with radial links pointing to various solutions and saying, "with your boxes, you can diverge as much as you want. I need a concept of rotor; well I have this, this and that concept..."

Integration of Tools for the Whole Design Process

Integrating all tools in a central platform is one aim of *CogEx*, but the limited resources for the project could only allow producing a subset. Participants made use of external softwares in parallel of CogEx for these missing functionalities. *One-Note* and *S-Note* were used for handwriting and sketching, *Teamwork* for team tasks, *Google tasks* for personal tasks, and *Facebook* for some collaborative exchanges. Participants were asked about the importance to integrate everything in a unique platform, and every participant recognized that this is a very interesting aspect of the platform. When discussing the intents of the *CogEx* platform, **V** stated that "a big advantage of that (*CogEx*), is that everything is at the same place." **X** commented that "if we can use everything, all in one, it is always better. Just for school, we are asked to work in *Microsoft 365*, in parallel I have my *Google Drive*…"

Community Drive

The current study focused on the individual use of *CogEx* and the collaborative features were deactivated in the pilot studies. Nonetheless, as outlined in the conceptual framework, the community aspect is a major facet and participants naturally mentioned its importance for *CogEx* to be more useful and attractive. **X** summarized it this way, "If everybody uses the same thing, that is certainly a plus. It would encourage me to use it more. If everybody uses it, it makes us work together." Participants **W** warned that it may be hard to bring everybody in because they feel that not everyone is willing to take the time to get accustomed to such a new tool, "I don't have the impression that the effort to learn a new software, that the motivation is there (for everybody)." This participant still think that, "if everyone can have the same software that all work together to be able to communicate, that would work much better than let's say Facebook." For participant **Z** the logbook takes all its importance when comes the time to share information, "What's important to have in the logbook is all that can be easily transmitted […] you want him (a collaborator) to be able to see your map, your variables, what it all means."

Engineering Data Needs

Data usage is mostly consistent with previous research of data usage (Hicks 2005; McAlpine et al. 2006). Charts/Graphs is the only type of data from those studies that was not mentioned in the pilot studies. The study confirmed the requirements for managing all these data types, but it also shows that the platform must offer a competitive set of tools, or else users resort to external applications and it breaks the goal of centralizing all data.

Participants were asked what type of information they used the most in their work, including what they could not store in the platform. The highest use was almost always for tasks and fast memos, often in the context of meetings. Participant **B** suggested that "tasks are good, but I would need them to be linked with my calendar to use them well", which is an idea also proposed by **D**.

In *CogEx*, a memo is available in the form of a text box or a comment entity. However, users need something faster, closer to the speed of opening a paper logbook and jotting something down. For this, the application must open faster, perhaps without the need to login every time, and there as to be a way to create a note that will be placed latter in an appropriate place. It would be ideal to also have a simplified application for the phone for those frequent ideas that arise outside work context. Creativity studies propose that after conscious work on a problem, ideas keep forming unconsciously and may result at any later time in an illumination for a solution. This phenomenon is called the incubation effect (Christensen 2005) and is a normal part of creativity.

The next important types of information are small drawings and handwritten annotations, expressed in statements such as "what I often do is sketches, some small drawings" (**X**) or "it's important to do your basic sketch and if you have an idea, you write it in" (**V**). Workspace of participants also shows pictures, most likely copied from the web.

Some participants were interested in managing files, particularly Office documents and CAD files. Participant **A** explained how he managed his CAD work, "I do a lot of CAD so I use snapshots of my CAD (placed) in cascade to show the evolution. I show assembly, not the parts, because that would be too long."

CogEx can upload and download files on the cloud. Although this works fine for documents that are meant to be read, it is insufficient for files that will change. Office documents and CAD files in particular need to be well integrated. The files must ideally work well in a collaborative context. The plan is to use existing technologies such as *Office 365* and *Dropbox* to offer appropriate support.

Also, there is a frequent interest for references to websites and literature reference. There are mixed opinions if it should stay as bookmarks in the browser or be saved in the project space. One solution to bring both parties together might be to synchronize the *CogEx* bookmarks with a special folder of the browser's bookmarks.

Few participants mentioned they needed to write down calculations, which was primarily made from handwriting as shown in the work of **L** in figure 3 c). Other types of useful information mentioned are videos, tables, contact information, hypothesis and comments from teachers.

DISCUSSION

The Human Operation Level

Interface is designed with a simple set of creation tools always visible. This simple non-modal design suggested by Balagtas-Fernandez, Forrai, and Hussmann (2009) gave good results, with no complaints about the software being hard to understand and use. Coherent actions for similar interactions and a paradigm based on manipulable objects were satisfactory. Discussions with the participants allowed to identify that the visual presentation could be improved by inverting the order in the navigation list to make it more intuitive and by compensating zoomed out text with bigger and more readable text. In the same vein, it was suggested that the interaction on items that are too small for manipulations with fingers should be disabled, since interaction is not precise enough and is frequently not desired. These changes are technically easy and the overall conclusion is that the simplicity and affordance qualities pursued in designing the interface are successful.

Studies have shown that sketching is part of the creative process, and without it, the quality of design solutions decreases (Stacey and Lauche 2005). A dynamic interplay arises when the designer sketches. Some lines are exploratory or ambiguous and can be reinterpreted to elaborate the solution (Stacey and Eckert 2003). Our effort to support handwriting in *CogEx* has been insufficient and the current study corroborates with the fact that it is a fundamental tool for conceptual and embodiment design phases. An efficient handwriting input is thus identified as a priority for the future of *CogEx*. Our pilot projects with tablets also highlighted how the virtual keyboard is not efficient and hides a lot of the work space. The stylus is the preferred way to write if no physical keyboard is connected. Efficient technologies are available to detect and transcribe handwritten text (*MyScript* 2017). This is an interesting avenue and could allow capturing text from handwriting so that the virtual keyboard is never used.

A tablet is a portable device with good potential for sketching input. It was found that the platform still needs to work on PC, or at least it needs to offer a bridge, since tasks such as CAD, document editing and web browsing are preferably performed on a computer.

The potential of the extended concept map to organize all design work is explored in this study. There are abundant studies on the use of concept mapping in academic contexts (McClure, Sonak, and Suen 1999; Rosas and Kane 2012) and the present study supposed that students would naturally use the principle of concepts connected with named links or arrows. However, this study shows only little use of relations between concepts and students tended to organize mainly with nesting and spacial grouping. This suggests that the nesting mechanism and the ability of placing concepts in space is natural or takes less effort. Nesting generally conveys a meaning that can be spelled out as “this is a part of” or “this is in the category”. Nonetheless, graphical arrows with a short phrase to link concepts can convey valuable additional information, such as design rationale. As with any new tool, some effort needs to be invested to learn and exploit it fully. It could be part of the learning strategies to make mandatory the use of named relations to convey more meaning. Moreover, with long-term usage, the user will see more payoff from is thoughtful organization and this will be a source of motivation to keep exploiting the full power of *CogEx*. Overall, the study confirms that the extended concept map as a good potential to organize all design work with multiple advantages over the chronological organization. Participants found that it offers a more logical organization that helps in finding work and evolving from existing work. It also offers an overview at various levels of details.

Designer Action Level

The action level is about higher cognitive process, such as problem solving and goal directed learning. Logbook usage and all the various data types are also included in action level since they are recurring throughout the whole design activity. C-K theory explains design at the action level with a set of operations between knowledge space and concept space (Hatchuel and Weil 2002). *CogEx* suggests translating this by splitting the workspace in two and managing project related data in one space, and the knowledge base in the other. The study shows that in practice it is not that simple. Concept-knowledge division was not much used. A first reason is that there is not much benefit on the short-term with a single project and a mostly empty knowledge space. Besides, starting the structure of knowledge from a blank space was hard for many students. It was suggested that a minimal template could help in alleviating this white page syndrome. Nonetheless, most participants said that they foresee the power of evolving a separate knowledge space to build and improve reusable knowledge. It would be interesting to use the tool in education to build and relate knowledge during courses and through the curriculum. This would build a knowledge base that can be related to practical work later during integrative projects.

An important finding is that the C-K spaces splits information in two places and it can actually slow down design. Moving from one space to the other requires changing the focus of attention and inevitably comes with a cost (Monsell 2003). The space switching cost needs to be removed, and we suggest that in a design session, concepts and knowledge should be created in the same space, without distinctions or possibly with a tag to identify knowledge. It is only when it comes time to reorganizing and reviewing that the user should place things that he feels should go in the knowledge space.

We conclude from our study that the C-K spaces do have the potential to organize and improve design work and to support learning, but splitting the work in two spaces does not work well. It needs to be implemented in such a way that splitting is not disruptive. This preliminary study justifies a future study to quantify long-term benefits in the academic context for the C-K organization with a non-disruptive work flow.

Design Tasks Level

A parallel can be made between the tasks and the stages of design described in Howard, Culley, and Dekoninck (2008). The present study focuses on conceptual and embodiment design phases.

It also includes planning. One of the goals of the platform is to centralize all design data and thus integrate most tasks of the design activity. Although the platform still needs work for this goal, the interviews confirmed the value of this objective.

For conceptual and embodiment design phases, this study demonstrates the potential of the extended concept map to allow the design to evolve over the existing data, to convey the design rationale, and to represent an overview of the problem. Only a few students took time to add design rationale information, but this is no surprise, as it represents extra work that would not appear in the paper either. It could be made mandatory though.

For task management, most participants resorted to an external application, such as *Teamwork* and *Google tasks*. The *CogEx* project evolved with limited resources and the planning functionalities were probably not good enough compared to available dedicated software. It was found that most participants mostly used simple tasks that they could organize and that could be shared through the team. *CogEx* task management needs to be improved to offer a flexible list of tasks that can be shared across the team. The study shows that tasks are mostly assigned during meetings and it must be fast to create and manage them. There are advantages in having the task system integrated in *CogEx*, as it allows contextualizing tasks with real work. For the collaborative aspect, the task system helps to follow labor division and can be linked to any valuable data inside *CogEx*.

Community

Although the pilot studies did not intend to study the collaborative aspect, our conceptual framework of the design activity gives a strong place to the community and it still is a major factor in the design team. Participants generally agree that the collaborative aspect of the tool will be a powerful feature. Some mentioned that a big leap in motivation to use the tool would come from usage across the team.

CONCLUSION

The *CogEx* platform was designed to replace the paper logbook used by design engineers. *CogEx* does not aim to replicate the paper logbook in a digital form. Instead, it proposes radically different ways of organizing design work to harness the power of modern computer engineering. This paper presents a qualitative study that explored the potential of *CogEx* in an undergraduate capstone design project. The conclusion is that the extended concept map can manage all design work and it is an improvement compared to the chronological organization of traditional logbook by helping to find information and by allowing evolution of the design from existing work. It also gives a good overview of the content and provides a visual representation that can convey design rationale. It also identified improvements to adapt the platform for individual designers.

The study confirms that integration of all the work in one central place is highly valuable. However, the tools must be comparable in performance to the offerings on the market and external documents, such as Office documents and CAD documents, should be easy to open and edit from the platform. Otherwise, users resort to other solutions in parallel and integration of all data is lost. Discussions with participants reveal that the priorities in *CogEx* are to integrate an efficient sketching system with the stylus and more options for task management.

There is an interesting potential to organize project information in one space and all knowledge in another space, as it allows growing and interconnecting student knowledge across his projects. The study shows that participants did not use the knowledge space much because there was no short-term benefit and it was disruptive to move to the knowledge space when work was going on in the concept space. If the C-K organization is to be kept, the work flow must be improved, perhaps by allowing knowledge creation inside the concept space while designing, and only later reorganizing it. The full power of the C-K organization is likely to show-up with longer usage through multiple curricular and co-curricular projects and with *CogEx* in academic courses. This motivates a future long-term study.

The current study focused on individual usage and is used to improve *CogEx* so it is fit to replace the paper logbook in capstone design projects. However, once the platform is fully functional for individual usage, our next step is to unlock the collaboration mechanism already built in and study how they perform with a pilot project engaging a full project team. Once completed, this platform is good for designers, but also interesting for studying them. In fact, a strength for designers is the centralization of all information, including collaboration information. All these data will naturally be saved in a format fit for all sorts of analysis.

REFERENCES

Balagtas-Fernandez, Florence, Jenny Forrai, and Heinrich Hussmann. 2009. "Evaluation of User Interface Design and Input Methods for Applications on Mobile Touch Screen Devices." In *SpringerLink*, 243–46. Springer, Berlin, Heidelberg.

Cho, Kwangsu, and Charles MacArthur. 2010. "Student Revision with Peer and Expert Reviewing." *Learning and Instruction*, Unravelling Peer Assessment, 20 (4): 328–38.

Christensen, B. T. 2005. "Creative Cognition: Analogy and Incubation." Citeseer.

Dym, Clive L., Alice M. Agogino, Ozgur Eris, Daniel D. Frey, and Larry J. Leifer. 2005. "Engineering Design Thinking, Teaching, and Learning." *Journal of Engineering Education* 94 (1): 103–20.

Eblen-Zayas, Melissa. 2015. "Comparing Electronic and Traditional Lab Notebooks in the Advanced Lab." In, 28–31. American Association of Physics Teachers. https://advlabs.aapt.org/document/ServeFile.cfm?ID=13799&DocID=4219

Fauconnier, G., and M. Turner. 1998. “Conceptual Integration Networks.” *Cognitive Science* 22 (2): 133–187.

Feltovich, P. J., M. J. Prietula, and K. A. Ericsson. 2006. “Studies of Expertise from Psychological Perspectives.” In *The Cambridge Handbook of Expertise and Expert Performance*, 41–67.

Gouda, Pishoy. 2016. “The Need for Logbooks to Evolve in the Undergraduate Medical Setting.” *Perspectives on Medical Education* 5 (1): 65–65. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4754216/

Hatchuel, Armand, and Benoît Weil. 2002. “C-K Theory : Notions and Applications of a Unified Design Theory.” In *Proceedings of the Herbert Simon International Conference on « Design Sciences »*. Lyon, France.

Hicks, G. Huet B. J. 2005. “A Study of the Information Content of the Engineer’s Logbook.” *DS 35: Proceedings ICED 05, the 15th International Conference on Engineering Design, Melbourne, Australia,*

Howard, T. J., S. J. Culley, and E. Dekoninck. 2008. “Describing the Creative Design Process by the Integration of Engineering Design and Cognitive Psychology Literature.” *Design Studies* 29 (2): 160–80.

Hurst, Ada, and Oscar G. Nespoli. 2015. “Peer Review in Capstone Design Courses: An Implementation Using Progress Update Meetings.” *International Journal of Engineering Education* 31 (6): 1799–1809.

McAlpine, H., B. J. Hicks, G. Huet, and S.J. Culley. 2006. “An Investigation into the Use and Content of the Engineer’s Logbook.” *Design Studies* 27 (4): 481–504.

McClure, John R., Brian Sonak, and Hoi K. Suen. 1999. “Concept Map Assessment of Classroom Learning: Reliability, Validity, and Logistical Practicality.” *Journal of Research in Science Teaching* 36 (4): 475–492. *http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.598.5212&rep=rep1&type=pdf*

MyScript. 2017. *http://myscript.com/.*

Novak, Joseph D., and Alberto J. Canas. 2008. “The Theory Underlying Concept Maps and How to Construct and Use Them.” Technical. Pensacola, Florida: Florida Institute for Human and Machine Cognition. *http://cmap.ihmc.us/docs/theory-of-concept-maps*

Oleksik, Gerard, Natasa Milic-Frayling, and Rachel Jones. 2014. “Study of Electronic Lab Notebook Design and Practices That Emerged in a Collaborative Scientific Environment.” In *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing*, 120–133. CSCW ’14. New York, NY, USA: ACM

Rosas, Scott R., and Mary Kane. 2012. “Quality and Rigor of the Concept Mapping Methodology: A Pooled Study Analysis.” *Evaluation and Program Planning*, Safer Schools and Healthier Students: Findings from the National Evaluation of the Safe Schools and Healthy Students, 35 (2): 236–45.

Sanson-Fisher, Robert W., and Marita C. Lynagh. 2005. “Problem-Based Learning: A Dissemination Success Story?” *Medical Journal of Australia* 183 (5).

Stacey, M., and C. Eckert. 2003. “Against Ambiguity.” *Computer Supported Cooperative Work (CSCW)* 12 (2): 153–183.

Stacey, M., and K. Lauche. 2005. “Thinking and Representing in Design.” *Design Process Improvement*, 198–229.

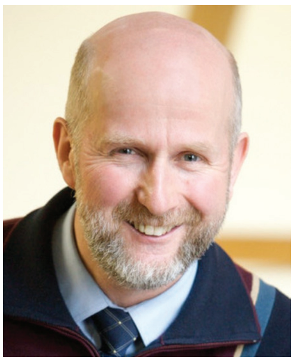
Tabard, Aurélien, Wendy E. Mackay, and Evelyn Eastmond. 2008. “From Individual to Collaborative: The Evolution of Prism, a Hybrid Laboratory Notebook.” In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work*, 569–578. CSCW ’08. New York, NY

Vygotsky, L. S. 1978. *Mind in Society*. Cambridge, MA: Harvard University Press.

Yue, F. 2016. “A Study of Student Information Management Software.” In *2016 IEEE International Conference of Online Analysis and Computing Science (ICOACS)*, 393–96.

AUTHORS

David Foley developed the CogEx platform in the context of his PhD studies in Mechanical Engineering at Université de Sherbrooke. He is lecturer for design courses and also works on founding a company to benefit knowledge workers from the CogEx platform. Besides scholarly work, he is renowned as an elite pole vault athlete and coach.



François Charron has been a Mechanical Engineering professor at Université de Sherbrooke since 1991. Before then, he worked for Spar Aerospace in Montréal where he was involved in various international space programs. He is mainly teaching design projects and he is currently the head of the Mechanical Engineering Department.

Jean-Sébastien Plante is a Professor of Mechanical Engineering at Université de Sherbrooke since 2007 following doctoral studies in robotics at MIT. He his the Canada Research Chair on Smart-Fluid Actuators and his the co-director of a design-oriented research lab teaming 8 professors called “Createk”. He is also an entrepreneur being the co-founder and Chief Technology Officer of Exonetik, a company developing high-performance actuator systems that brings human-like motion to machines.