Conceptual design in the cloud: technology use and teamwork under COVID-19

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***Abstract*– COVID-19 brought profound changes to tertiary education, the main one being the need to move from face-to-face training processes to tele-education in a short time. In this context, engineering education experienced a new level of complexity, particularly in contexts of project-based learning environments, where students must significantly interact with peers and make group decisions. Added to this context, was the long-triggered need by the industry to train engineers capable of dealing with broad, non-technical issues. Hence, the ability to telework has become critical for engineering students, particularly to be able to communicate and make teamwork decisions effectively and efficiently in online environments.**

In this work, we investigated qualitatively how a group of students responded to the rapid transition from formal classroom teaching to remote learning, particularly in the context of responding with conceptual designs to the requirements of project-based courses. The response of sixty-two Engineering Design students from a Chilean technical university is analyzed regarding the usability of the technological tools they used to conceptually solve problems online and how they perceive the teamwork they were able to achieve using these tools.

Conceptual design, design engineering, online education, usability, project-based learning,

I. INTRODUCTION

A. Pandemic and virtuality

In recent years, the Digital Transformation processes and the challenges they present for society and the economy have attracted the attention of government, business and academic circles [8]. On the one hand, Digital Transformation, driven by the concept of Industry 4.0, has radically influenced the labor market, presenting new global scenarios for technological entrepreneurship and employment [25]. On the other hand, in higher education a race against time has been promoted to implement agendas associated with new digital environments for the teaching-learning process [18, 29].

In the case of Chile, both the health crises due to the COVID-19 pandemic and the social outbreak of 2019 were added together, seriously impacting the teaching-learning experience and accelerating the implementation of strategies for online teaching throughout the context of higher education [22, 5].

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B. Online collaboration and teamwork

In addition to the contingencies due to the pandemic, recent decades have shown the need to respond around the priority training of professional skills [15]. In particular, the industry has suggested that engineering students, in addition to developing technical skills, must have communication and persuasion skills, skills to lead and work effectively in groups, understand the non-technical elements that affect engineering decisions and, in the last time, the ability to adequately practice the profession in remote work environments [16, 17].

Particularly, decisions associated with engineering design processes of products and services, can be associated with complex work environments, open and ill-defined problems, incomplete information and many possibilities of adequate solutions or responses [9]. In this context, many research efforts have been made to investigate what are the knowledge bases, skills and competencies required to address work successfully when new solutions must be designed from the beginning of the design process (i.e. conceptual design) and into full development [24].

However, in engineering education less is known about how to properly adapt teaching strategies to achieve effective learning and performance in remote environments where design-skills are central [7]. Hence, a first step in this direction will be to understand the current state of perception that engineering students have regarding the most used tools for teleworking in design and how this action has been carried out. The research questions are then posed as:

- *RQ1: 1: How do students perceive remote tools for conceptual design?*
- *RQ2: How do students perceive that teamwork has been affected by the online use of tools?*

Given the lack of time and increasing workload faced by university instructors, exploring these outputs will provide an insight into how online project-based courses can provide students with better technological support both for conceptual design and teamwork.

II. LITERATURE REVIEW

A. Conceptual design phases

In the engineering design community, the definition of a conceptual design process is key to understanding how a designer moves from abstract needs to objective models in a tangible world [2]. Conceptual design is a stage in which functions are established and the initial solutions are proposed and developed [12].

Different research efforts have been made in order to define phases of the conceptual design, always considering it as a specific part of a larger design process cycle [4]. Conceptual design at large has been associated with the early stages of design ideation and exploratory design. Table 1 summarizes some of the general phases of conceptual design according to a set of authors.

TABLE I
SUMMARY OF CONCEPTUAL DESIGN PHASES

Author, year	Phases of conceptual design
Hay et al, 2020	1. Open-ended design tasks: Designers are asked to generate (ideate) concepts in response to open-ended problems, 2. Identification of explored problems and solutions: Concept sketches are systematically classified using a qualitative coding process. 3. Evaluation of exploratory ideation performance. Each designer's performance is quantified in terms of: (i) how many different problem interpretations they considered (breadth of exploration); and (ii) the extent to which the solutions they generated are new compared to the solutions produced by others designers in the study (solution novelty).
Chen, 2018	1. Identification of functional requirements is defined as the minimum set of independent requirement that completely characterizes the function needs of a product 2. Definition of basic functions: functions that correspond to the functional requirement definition. 3. Design of functional units: elementary entity for achieving some basic functions 4. Conceptual System: The output of the design system where functional units are integrated and analyzed.
Chen, Zhao et al, 2015	1. 7. Clarify: this stage is responsible for clarifying a need into a desired function. 2. Synthetize: this stage is responsible for generating the abstract principle of a solution concept for achieving a desired function. 3. Embodiment: preliminary model system is generated 4. Analysis: analyze the system to verify whether the model things determined before and the problematic environment can form a model system as expected

From Table 1 it is possible to observe the same pattern, this is, conceptual design starts with a problem and its general requirements, and then moves on to phases that aim to add functionality to an idea or series of ideas, until these representations mature into a solution.

From a problem standpoint, conceptual design can be related to two perspectives [6]. On one side it can be solution-focused, this is when designers generate solutions to solve a fixed problem, with clear specifications of the desired output. On the other hand, conceptual design can be an exploratory process in which designers consider different interpretations or answers to an open-ended problem and generate a set of linked solutions.

B. Tools for conceptual design in the cloud

From a technologically supportive perspective, conceptual design deals with a series of phases that require communicative tools in order to aid the transfer of ideas from a designer's mind into the objective world [23]. Different authors have described a series of tools in order to enhance conceptual design. Table 2 summarizes relevant research with regards to technological tools that can serve from planning, through need understanding to form modelling.

TABLE II
SUMMARY OF TECHNOLOGICAL TOOLS FOR CONCEPTUAL DESIGN

Author, year	Action required	Tool
McMahon, 2016	Work planning and task definition	MS-Project MS-Office
Coley et al., 2007	Documenting meetings, free-form information gathering	MS One-note Knowledge-Enhanced Notes
Tovey, 2002	Modeling artefact characteristics (form, surface, texture)	CAD-CAM softwares
Sivanathan, Ritchie & Lim, 2017	Team-based design 'reviews'	Virtual Aided Design Engineering Review
Wlazlak, Eriksson, Johansson & Glenn 2019	Convey information and establish mutual understanding among actors in a distributed environment	Post-it notes
Marheineke, Habicht, Möslein, 2016	Shared understanding in virtual innovation communities	Virtual whiteboard with boundary objects
Li, McMahon, Newnes, 2009	Annotation content and/or extra informacion	Annotation technology for pictures, pdfs 3D annotation

As observed from Table 2, any tool for information capture, analysis and post-processing is useful, due to the intensive handling of information during the conceptual design process. These tools can serve in both problem-oriented and exploratory-based contexts.

As teams gather to start a conceptual design process a wide array of challenges will emerge, most of them are communication related due to the information-intensive nature of the process [12]. The effectiveness of communication is affected due to the nature of the detail-oriented nature of the design process. This is the reason why drawings and/or pictures are so fundamental to the effectiveness of the communicative process, since they can embed more detail into the discussion [14].

III. METHOD

A. *Conceptual design definition*

We started by defining a conceptual design process related to the coursework in which students engaged in our curriculum. Figure 1 summarizes the process we outlined.

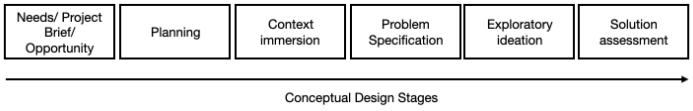

Fig. 1 Definition of Conceptual Design Stages.

Each stage is defined as:

- Needs/Project Brief/Opportunity: Each project starts by understanding the need scenario of a user or group of users. In some cases, such as when working with industry partners, a "Project Brief" is provided. Additionally, teams need to understand the stakeholders, outlining the opportunity dimension for all the actors linked to the project.
- Planning: Each team of students confronts the need to plan their roles in the project and organizes a set of activities ahead of time.
- Context immersion: Stage related to information and overall documentation gathering in order to understand user needs and problems.
- Problem Specification: After context immersion teams should be able to re-define the problem with regards to the information and documentation gathered.
- Exploratory Ideation: The last stage is related to idea development, in this phase students explore different solutions to the project in the form of drawings, 3D models and early prototypes.

From here we were able to map the current tools that are the most used for conceptual design.

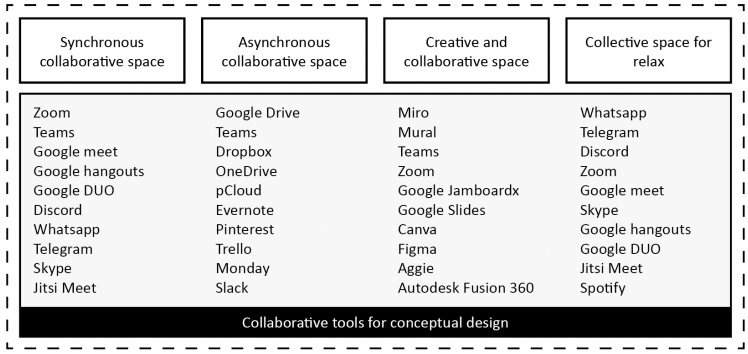

Fig. 2 Collaborative tools for conceptual design.

B. *Survey design*

With a common understanding of the conceptual design process and the tools for remote work, we were able to design a survey for the study. Figure 3 summarizes the structure of the first four questions aimed at understanding research question 1: How do students perceive remote tools for conceptual design? For this we explored their perception of the usability of the tools they had been using for each of the conceptual design phases. Figure 2 summarizes the structure of the survey related to each research question.

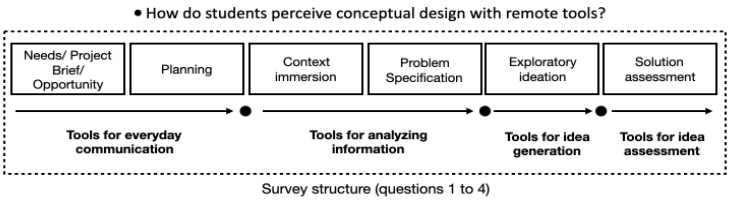

Fig. 3 Survey structure research question 1.

In the second part of the survey and in order to respond to research question 2 (*How do students perceive that teamwork has been affected by the online use of tools?*), we explored the satisfaction level with teamwork aspects such as peer-interaction, learning process and online learning. This is summarized in Figure 3.

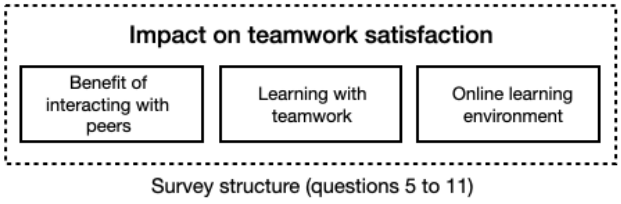

Fig. 4 Survey structure research question 1.

C. *Participants*

A total pool of 102 students from an engineering design program at a large chilean technical university were invited to participate. This program has a 10-semester duration. The eligibility requirements were to have been involved in one of three cornerstone project-based courses during the second semester of 2020. Table 3 summarizes the courses involved, in which semester they are taught, how many students were

enrolled in each one and the number of respondents to the survey.

TABLE III
COURSES AND TOTAL NUMBER OF PARTICIPANTS

Course	Semester in the program	Number of students	Number of respondents	Response rate %
Product Studio II	4th	39	24	61
Product Studio IV	6th	48	32	66
Product Studio VI	8th	15	6	50
	Total	102	62	AVG: 59

The survey was built in Google forms and distributed by email to each of the 102 students. Follow-up messages by professors of the courses were made after 2-3 days of the first sending of email messages.

IV. RESULTS

A. RQ1: How do students perceive remote tools for conceptual design?

For research question 1 we were able to derive two aspects from the survey. The first one was the understanding of which are the most used tools for conceptual design by the students while working in project-based courses. With regards to the frequencies in order to enhance visualization of data we only show those softwares that have a frequency larger or equal than two users. The most used tools by students correspond to communication platforms: WhatsApp, Zoom and Discord are communication platforms through chat and / or video calls. In a second instance, students recognize the use of Google Drive and Microsoft Teams, platforms for storing and organizing documents. This is consistent with the need for students to communicate during the design processes to discuss their ideas and need to organize.

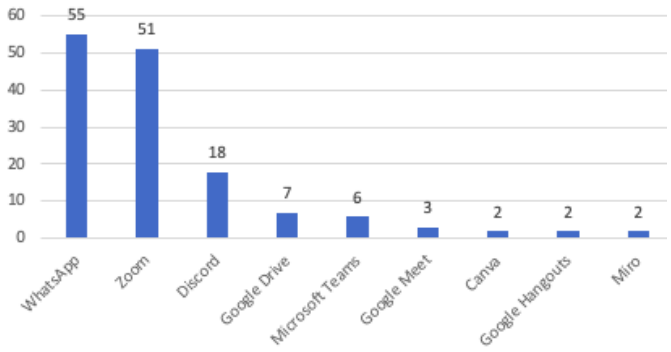

Fig. 5 Frequency graph of tools used for everyday communication.

To analyze information, most students use presentation design tools such as Canva, PowerPoint and Google Drive, since it allows them to visualize and arrange graphic elements, in line with the need to have access to drawings and/or pictures to the effectiveness of the communicative process. However, there are other tools such as Jamboard and Miró -online visual collaboration platforms for teamwork- that were created for collaborative work. In addition to the fact that Canva and PowerPoint are not optimized for real-time work, it can be concluded that students use them because they are familiar with them without considering whether they are the most efficient or not.

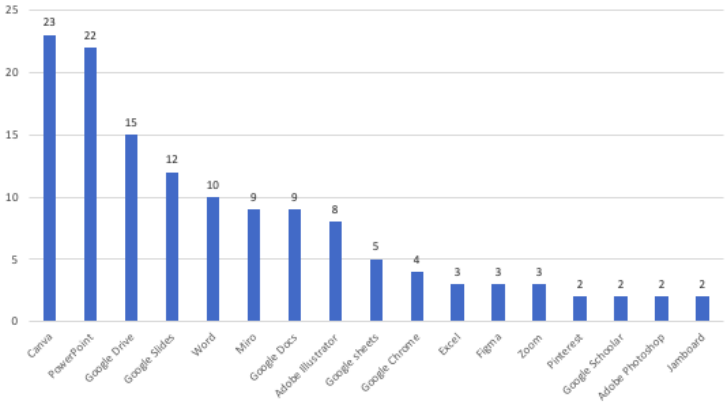

Fig. 6 Frequency graph of tools used for analyzing information.

To generate ideas, students mostly use communication platforms (Zoom, Whatsapp) and tools for visual collaborative work such as Miro, Canva, Google Drive, Jamboard, PowerPoint. They identify other graphic editing tools such as Adobe Illustrator, Adobe Photoshop, Autodesk Sketchbook and Procreate: these allow expression of ideas graphically through drawings or schemes. They use collaboration tools to a greater extent and complement their activities with specific personal work tools.

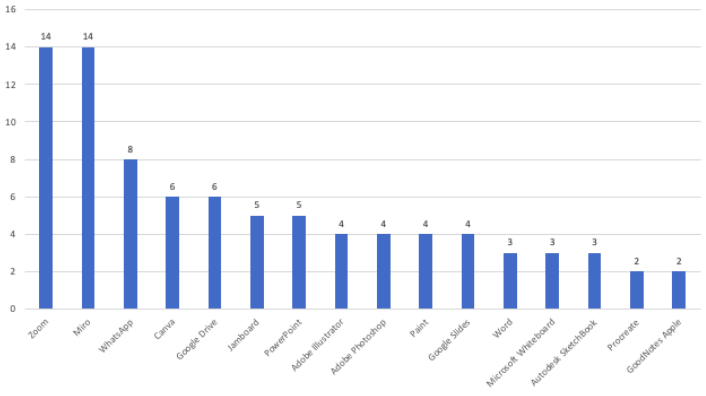

Fig. 7 Frequency graph of tools for idea generation.

For the evaluation of ideas, students identify tools for 3D prototyping (Autodesk Inventor suite, 3D Max and Fusion 360), 2D design (Adobe Illustrator, Photoshop) and wireframe design (Adobe XD, Figma). Analyzing these responses, students virtually prototype their ideas to evaluate them as a team. They

also identify various types of prototyping tools where they can choose the one that best suits their design needs.

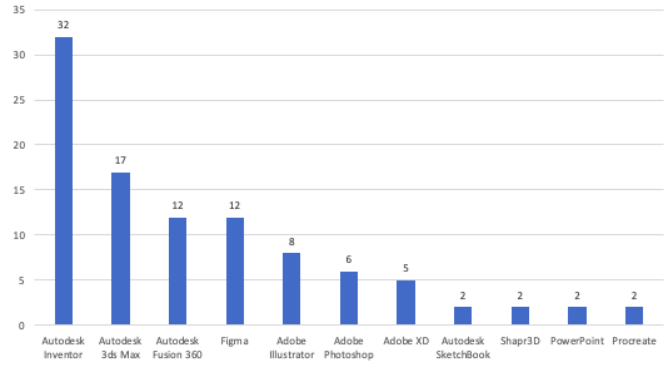

Fig. 8 Frequency graph of tools for idea assessment.

With regards to the perception of the usability of each of these groups of tools, students assessed them on a scale from 1 to 10. The general result is that around 60% of the students valued them as having a high usability (score 8 to 10). Table 4 summarizes the data for this assessment.

TABLE IV.
SUMMARY OF USABILITY SCORES

		Tools for initial and everyday communication %	Tools for analyzing information %	Tools for idea generation %	Tools for idea assessment %
Usability score	10	23	24,6	18,5	32,3
	9	16,9	20	21,5	21,5
	8	46,2	20	21,5	21,5
	7	6,2	20	23,1	7,7
	6	4,6	7,7	6,2	6,2
	5	0	4,6	6,2	4,6
	4	0	3,1	3,1	4,6
	3	1,5	0	0	0
	2	1,5	0	0	0
	1	0	0	0	1,5
		100	100	100	100

B. *RQ2: How do students perceive that teamwork has been affected by the online use of tools?*

Table 5 summarizes the results for the survey aimed at understanding students' perception of three dimensions: benefit of interacting with peers, learning with teamwork and an online learning environment. In general, it is possible to observe very high levels of agreement with each of the statements. Only a few have higher levels of disagreement. In this group we can mention:

- "Online teamwork helps my creative development" (23%): This displays that creative processes seem to still be rooted in individual processes and /or remote tools are not being able to fully cover the teamwork creative processes.
- "The use of online digital tools has allowed me to make the conceptual design better than in person" (26.1%): Still a group of students perceive that traditional classroom work better supports conceptual design. This is in line with the previous statement, in which it is possible to observe.

Neutrality with regards to some statements remains high, particularly in the case of statement number 11 ("Using online digital tools allows me to better solve conceptual design problems").

TABLE V
SURVEY RESULTS FOR TEAMWORK PERCEPTION WHILE USING ONLINE TOOLS FOR CONCEPTUAL DESIGN

	When working online in Project Studio Courses...	Agree %	Neutral %	Disagree %	Total %
Benefit of interacting with peers	1."Interacting with my teammates increases my motivation to learn"	67,7	18,5	13,9	100
	2. "I have benefited from the feedback from my colleagues to the idea / project"	66,1	23,1	10,8	100
	3. "The members of my team adequately share their knowledge during the teamwork process"	64,6	20	15,4	100
	4. "I like to work in a collaborative group with my teammates"	81,6	10,8	7,7	100
Learning with teamwork	5. "I enjoy the collaborative learning experience in activities with my entire course"	63,1	23,1	13,8	100
	6. "I enjoy the collaborative learning experience with my teammates"	70,7	18,5	10,8	100
	7. "Working with my team allows me to develop better quality projects than working individually "	64,6	26,2	9,3	100
Online learning environment	8. "Online teamwork helps my creative development"	52,3	24,6	23	100
	9. "I have gained skills to generate ideas"	55,4	26,2	18,5	100
	10. "The use of online digital tools has allowed me to make the conceptual design better than in person "	43,1	30,8	26,1	100
	11. "Using online digital tools allows me to better solve conceptual design problems "	49,2	38,5	12,3	100

V. DISCUSSION

A. *Social networking and new communication standards*

With regards to the tools in the technological landscape it is interesting to observe the emerging use of social media tools not only for communicating, but also for idea generation. Even platforms that emerged as support for the gaming communities are now being used because of its diverse integration of capabilities (chat, file sharing, communities) which seem to properly support the decision process [14]. It is interesting to observe how new technological players have made a strong presence during the last time. This is the case of ZOOM (versus Google Hangouts or Skype) for online meetings, and CANVA for development of infographics and presentations (versus MS Powerpoint or Google Slides). The usability assessment of all these platforms is high and therefore it seems improbable that students will return to platforms that were standard in the pre-pandemic era. Conceptual design in the cloud therefore is strongly influenced by the use of social media tools, which seem to be providing proper support to its underlying communicative process [12]. With regards to our results, teamwork has not been significantly affected by the use of online digital tools to solve conceptual design challenges, in other words, students have been able to maintain their communicative processes around the design by using technology [18]. There are several students that are neutral with regards to the benefit of peer interaction, the learning and online tool environment. These students have probably had more difficulties in adapting to the technological change due to baseline skills or maybe even because of poor internet-connection which has been a constant under COVID-19 [22].

These are issues to further explore in order to provide the appropriate skills scaffolding and/or technological support.

VI. CONCLUSION

This research is a first step into understanding how engineering education can better support project-based courses, particularly those where students must make conceptual design decisions in teamwork environments. We were able to understand the progressive replacement of technologies used by students to solve conceptual challenges and how they are affecting teamwork. From here it is possible to enhance future development of courses by scaffolding students' skills with some of these technological tools.

VII. LIMITATIONS

The study was able to cover the majority of students in the courses involved in conceptual design (average response rate 59%), however due to the application of the survey at the end of semester a number of students did not respond to the survey and their perceptions are unknown.

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