The Digitalization of Engineering Curricula: defining the categories that preserve constructive alignment

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Abstract. The COVID-19 pandemic has significantly changed the education domain boosting its digitalization. A pedagogical shift from live to virtual teaching, learning, and assessment activities is the primary outcome of this transition. This work analyses two courses included in the Industrial Engineering program offered in two prominent European higher education institutions. The Constructive Alignment (CA) approach is the baseline of this work and is used to analyse how the Teaching and Learning Activities (TLAs) and the Assessment Tasks (ATs) of the selected courses are adjusted to maintain alignment with the Intended Learning Outcomes (ILOs) defined before the Digital Transition (DT). The main contribution is the definition of the relevant categories, i.e., *Technology, Interaction, and Time*, to guide the DT in engineering and beyond by maintaining the alignment on ILO-TLA-AT.

Keywords: Digitalization · Distance learning · Engineering · Constructive alignment

1 Introduction

Scientific publications discussing online/distance learning have significantly increased throughout the last decade [1]. The COVID-19 pandemic represented an unexpected condition that significantly changed people´s lifestyle along with the education domain boosting even further its digitalization, mostly at higher levels [2]. Distance learning is facilitating a pedagogical shift from live to virtual [3] as well as the adoption of digital technologies in education [4]. Therefore, online learning is becoming more popular as it may partially replace on-campus education [3]. In this new digital scenario, the change in teaching methodology will involve several thoughts and preparation [4]. The focus is now on the engagement of students, the instructor's role, and course design [1]. As for the course design, teachers have been challenged to comply with the Constructive

Alignment (CA) approach [5] which has become a dominant design pattern in education. The forced and the short notice digitalization of education due to the COVID-19 pandemic has challenged educators in designing Teaching and Learning Activities (TLAs) and Assessment Tasks (ATs) that would maintain the Intended Learning Outcomes (ILOs) - TLAs - ATs alignment established before digitalization. As argued by [6], teachers have made adjustments to their assessment approaches but still ensuring that the students have achieved the same ILOs. In terms of new teaching approaches, access to the same on-site course content is a priority.

In view of the above, this paper assesses two courses (i.e., *Scientific methodology* - SM - and *Manufacturing processes* - MP) selected from the Industrial Engineering study program offered in two prominent European higher education institutions (i.e., *KTH Royal Institute of Technology* and *University of Pisa* [7]). The CA approach is the baseline of this work and is used to analyse how the TLAs and ATs of the selected courses are adjusted to maintain alignment with the ILOs defined before the digital transition (DT). The main contribution is defining a set of categories to guide the DT in engineering and beyond by maintaining the alignment on ILO-TLA-AT (Figure 1).

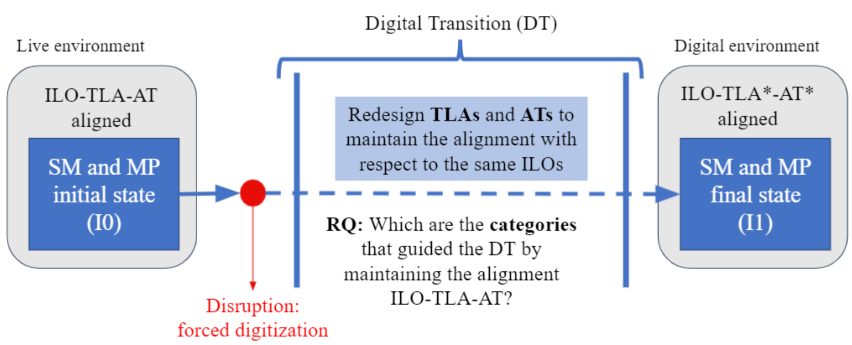

Fig. 1: Graphical representation of the definition of the Research Question (RQ) in the presented context. The star * indicates the redesigned TLA and AT after the DT.

2 Theoretical background

Teachers have been facing many challenges in course design. Among others, it is worth mentioning: mapping the course onto the study programs, ensuring that the course is consistent, and focusing on what the student does. Regarding this last challenge, the design approach called CA underpins the learners-centered courses. In particular, the CA is a design approach for outcome-based teaching and learning [5] based on two principles:

I. *The constructivist approach to learning:* the fundamental assumption is the centrality of the student in the learning process. Learning is an active process in which student constructs their knowledge [8] by bringing a combination of previous knowledge, assumptions, motives, and intentions [9]. This is called *accommodation* process of generating new knowledge, where the student re-frame pre-existing knowledge based on new ones [10]. Therefore, the process of learning focuses on what the student does [11] rather than what the teachers do. Recently, this constructivist approach has become dominant in the education domain.

II. *The designing of an aligned curriculum:* three are the basic concepts of an aligned curriculum:

- the **ILO**. The learners are provided with a set of clearly specified learning goals, i.e., the ILOs. These are expressed from the students´ perspective, identifying (1) a *verb*, i.e., it reflects the educational goal and related level of understanding required, (2) a *content*, i.e., the focal concept within the discipline, and (3) a *context*, i.e., the domain in which the content is studied.
- the **TLA**. Suitable TLAs are designed to engage the students and lead them to achieve the ILOs, by activating the verb conveyed in the ILOs. Each TLA may address a specific ILO.
- the **AT**. It is created to test the learners and give them feedback. The AT needs to reflect how well the material has to be learned. This is specified by the level of understanding which embeds the complexity required. The level of complexity can be described with the SOLO (Structure of Observed Learning Outcomes) taxonomy [12] that consists of five levels: pre-structural, uni-structural, multi-structural, relational, and extended abstract (Figure 2). This taxonomy provides a measure of the quality of assimilation [12] which is useful to design effective assessment.

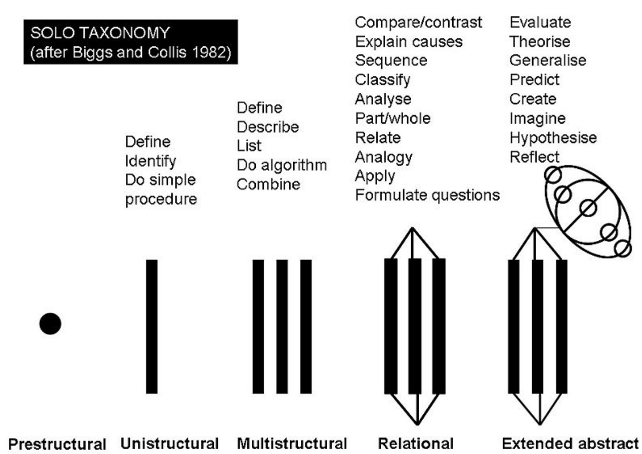

Fig. 2: The SOLO taxonomy, adopted from [12]

The alignment ILO-TLA-AT is realised with "action" verbs specified in the ILO that create a common link among the three elements [11]. These "action" verbs are selected looking at the modified Bloom taxonomy (Figure 3) [13].

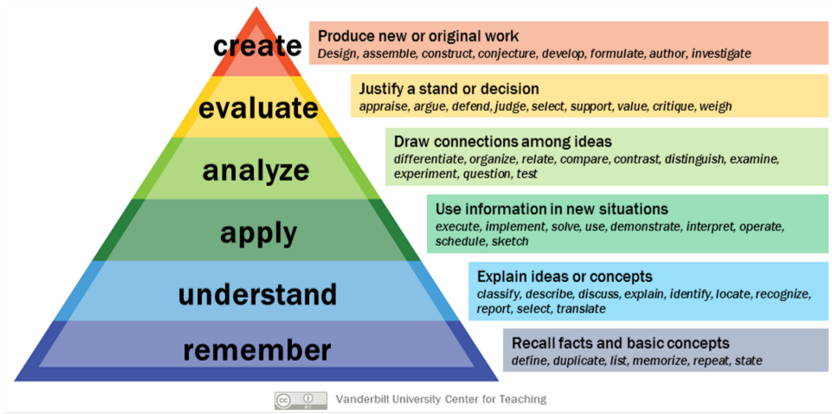

Fig. 3: The Bloom taxonomy, adopted from [13]

The taxonomy presents a classification of the learning objectives based on six different types of knowledge: remembering, understanding, applying, analyzing, evaluating, and creating. At each level, the taxonomy associates a set of verbs that activate the abilities necessary for a specific learning goal. For instance, remembering which demands for merely recalling facts and basic concepts is associated with verbs such as define or list; analyse which implies drawing connections among ideas is associated with verbs such as compare or examine.

Summarising, the CA can contribute to designing a learning approach that emphasises the students and promotes a deep approach to learning.

3 Experiment

The *Scientific methodology* course from Production Engineering at KTH (The Royal Institute of Technology) Sweden, and the *Manufacturing processes* course from the program of Management and Industrial Engineering at University of Pisa Italy, are considered for the analysis.

Section 3.1 provides an overview of the two selected courses analysed and its ILOs, TLAs and ATs. These courses represent the input data of the experiment conducted on the whole methodology. Section 3.2 presents the methodology adopted to investigate the main changes that occurred during the DT.

3.1 Description of the courses (ILO-TLA-AT)

Scientific Methodology course: aims at teaching the students how to design, perform and document personal research work. The activities are tailored to industrial and production engineering students who can use the knowledge and skills acquired hereby for their final thesis project. After completing the course with a passing grade, the student should be able to:

- ILO1. **Define** and **discuss** the nature of the research in relation to the two main domains: scientific methodology and engineering design, outlining their importance and use in the context of production engineering.
- ILO2. **Present** and **discuss** the evolution of thoughts from several aspects of the scientific domain such as definition, nature and progress of knowledge.
- ILO3. **Analyse** a scientific text and review the research question, the method and the conclusions.
- ILO4. **Structure**, carry out and document a research endeavour.
- ILO5. **Discuss** the origin of the scientific method as a result of the evolution of the human approach to the main philosophical problems, emphasizing the sociological and economic problems.
- ILO6. **Gather** information and elaborate a strategy to qualify and defend an opinion on a controversial topic, and **analyse** and **summarize** the following debate.

Manufacturing processes course: aims to provide knowledge on the main metalworking processes, starting from the recovery of metal scraps, their transformation into finished or semi-finished products, the optimization of the process parameters and the resulting quality of the product. After completing the course with a passing grade the student should be able to:

- ILO1. **Define** the main materials and **explain** their mechanical and thermophysical behaviour resulting from conventional manufacturing processes.
- ILO2. **Describe**, **model** and **define** the main conventional manufacturing processes (machining, casting, forming and welding).
- ILO3. **Present** and **discuss** the macro and microgeometrical metrology methods and techniques for the quality assessment of the resulting parts.
- ILO4. **Compare** and **select** conventional machining processes, machines specifications and configuration, production strategy, tools, fixtures and process parameters to manufacture a part, starting from a given mechanical drawing and its possible modifications to prevent defects, improve the mechanical properties and reduce costs.
- ILO5. **Develop** a technical report including process plan, process simulation and costing analysis for a given mechanical part.

The ILOs defined for each course are an important input to define TLAs and ATs. TLAs and ATs are designed taking as a reference the Bloom taxonomy (Fig. 3), and are summarised in Table 1 and 2 respectively for *Scientific methodology* and *Manufacturing processes.*

Table 1: The digital TLAs and ATs of the course *Scientific methodology* from Production Engineering at KTH (Sweden).

ILOs	**TLAs**	**ATs**
ILO1	**TLA1.1** Lectures: Present the scientific methodology and engineering design in a production context.	**AT1.1** Final examination: Answer questions regarding the scientific methodology and engineering design.
	TLA1.2 Class work: Encourage discussion on the presented methodology and engineering design.	**AT1.2** Group work: Discuss in groups on methodology and engineering design.
	TLA1.3 Guest seminars: Present the scientific methodology and engineering design in a production context. Encourage discussion on the presented methodology and engineering design.	**AT1.3** Written reflections: Write a report on the seminars content and reflect about the main message of the seminars.
ILO2	**TLA2.1** Lectures: Present the different aspects of the scientific domain.	**AT2.1** Final examination: Answer questions regarding the different aspects of the scientific domain.
	TLA2.2 Class work: Encourage discussion on the different aspects of the scientific domain.	**AT2.2** Group work: Discuss in group on the different aspects of the scientific domain.
ILO3	**TLA3.1** Lectures: Explain the general principles of scientific writing and guidelines for the analysis of a scientific text.	**AT3.1** Group work: Report the analysis and the critics of the formal structures and the layout of the contents of a scientific text.
	TLA3.2 Homework: Analysis of a scientific text and critically assess each section of the text.	**AT3.2** Group work: Report the analysis and the critics of the formal structures and the layout of the contents of a scientific text.
ILO4	**TLA4.1** Lecture: Explain how to structure, carry out and organize a research endeavour.	**AT4.1** Oral presentation: group presentation in front of the class that summarises the work.
	TLA4.2 Homework: Collect and structure information on the proposed topics. Prepare a oral presentation.	**AT4.2** Oral presentation: group presentation in front of the class that summarises the work.
ILO5	**TLA5.1** Lectures: Present the main philosophical problems.	**AT5.1** Final examination: Answer questions regarding the main philosophical problems.
	TLA5.2 Class work: Encourage discussion on the presented philosophical problems.	**AT5.2** Group work: Discuss in group the philosophical problems.
ILO6	**TLA6.1** Lecture: Present how to plan and execute all the activities related with a debate.	**AT6.1** Group work: the groups plan and debate on the proposed topics following the activities presented.
	TLA6.2 Homework: Collect and structure information on the proposed debate topics. Prepare a oral presentation.	**AT6.2** Oral presentation: group presentation in front of the class that summarises the result of the debate.

Table 2: The digital TLAs and ATs of the course *Manufacturing processes* from the program of Management and Industrial Engineering at University of Pisa (Italy). Final exams are carried out in seven tests during the year after the class is ended.

ILOs	TLAs	ATs
ILO1	**TLA1** Lectures: Present the structure of matter and transformations, properties and test methods, metal alloys and phase diagrams, standard terminology, notions of continuum mechanics properties of materials.	**AT1** Oral examination: Answer question regarding main material presented.
ILO2	**TLA2.1** Lectures: Present the main metalworking processes, the beyond mathematical models, the tools used, the manual and automatic machines and the equipment.	**AT2.1** Written essay/quiz: Answer theoretical questions regarding the main manufacturing processes presented.
	TLA2.2 Lab demonstrations: Present manufacturing process process via practical demonstration at the manufacturing lab's machines.	**AT2.2** Numerical exercise: Develop a process plan (process operations, parameters ad specifications) for a given part.
ILO3	**TLA3.1** Lectures: Present methodology, tools and machines for micro and macro geometric measurements, characterization of the artifacts (tolerances), via manual or automatic way.	**AT3.1** Oral examination: Answer theoretical questions regarding quality control and metrology.
	TLA3.2 Lab demonstrations: Present quality control machines and tools via practical demonstration at the metrology lab.	**AT3.2** Written essay/quiz: Answer theoretical questions regarding the main quality control approaches presented.
ILO4	**TLA4** Lectures: Provide examples of manufacturing processes, machines, parameters, and material selection in a real case study via multi-criteria generation and selection.	**AT4** Info graphic: Query, discuss with peers, and produce info graphic to explain, describe and visualize the main criteria in the selection process.
ILO5	**TLA5.1** Seminars: Set project work groups, explaining timing, tools, and expected outcome via a case study.	**AT5.1** Project work: Provide a technical report including process plan, simulation, verification, cost analysis on the selected mechanical part.
	TLA5.2 Class work: Encourage discussion on the use of collaborative tools for remote collaboration during the project group activity.	**AT5.2** Discussion: Listed, query and discuss with peers and professor.

3.2 Methodology

This section describes the inductive method developed to identify the categories that may be accounted for during the transition to digital education, ensuring alignment with ILO-TLA-AT.

A crucial aspect must be clarified before presenting the methodology steps. The two courses have proved to guarantee the ILO-TLA-AT alignment even after the forced DT due to the COVID-19 pandemic. In particular, as shown in Figure 4, the Gaussian grade´s distributions of the *Scientific methodology* and *Manufacturing processes* display similar trends: the mean and standard deviations show a low deviation before and after the DT. As for the mean values, the deviations is around +3,5% for *Scientific methodology*, and -0,9% for *Manufacturing processes*. As for the standard deviation both values decreased of around 22% for *Scientific methodology* and 5,5% for *Manufacturing processes* meaning the distributions of grades are less scattered. From the above, the students have proven to equally perform at the final assessment. Their performances were almost unaffected or even increased by the context and format changes. Therefore, the digital TLAs and ATs were designed coherently with the ILOs preserving the alignment ILO-TLA-AT. The two case studies can be thus considered for the application of the following method.

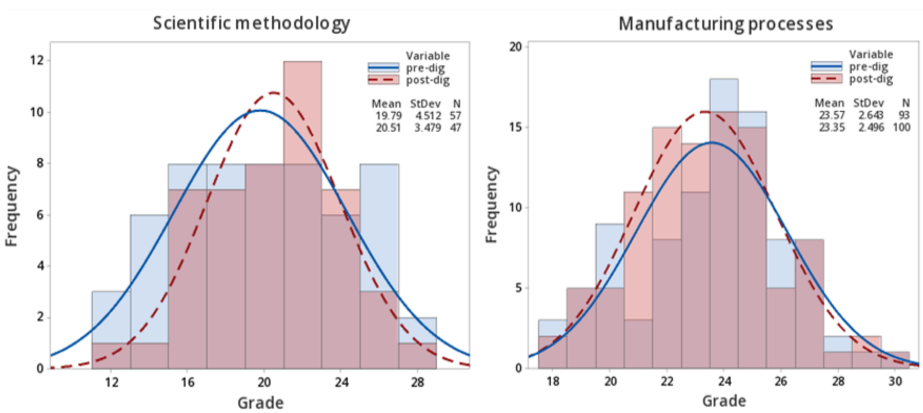

Fig. 4: The final grade´s distributions for both *Scientific methodology* and *Manufacturing processes* course before (2019) and after (2020) digitalization of TLA and AT. The number of students are: 57 and 47 before and after digitalization respectively for *Scientific methodology*; 93 and 100 before and after digitalization respectively for *Manufacturing processes*. Please note that the grade scale adopted in the two courses is different. The *Scientific methodology* adopts letter grades that have been converted into numerical grades for the sake of comparability. The numerical grades range from 28 (maximum) to 12 (minimum pass grade). The *Manufacturing processes* course adopts numerical grades where 30 is the maximum and 18 is the minimum pass grade.

The main adopted steps of the method are listed below:

1. For each course, all the DTs in teaching, learning, and assessment have been collected using a top-down generation approach. This approach covers all the transitions using the TLA and AT classes and its related sub-classes, i.e., lectures, guest seminars, homework, consultation hours, class work, practical lectures, remote examination, essay reports, and class presentation. The details are presented in Table 3 for the *Scientific methodology* course and Table 4 for the *Manufacturing processes* course.
2. For each sub-class, the related DTs have been organised in structured lists. Duplicates have been removed, and similar observations have been grouped.
3. Common patterns in the DTs have been identified in these structured lists and further investigated to group them into relevant categories. These categories have been labeled for semantic association as *Technology, Interaction and Time* (TIT).

As a result, *Technology, Interaction and Time* (TIT) are the main relevant categories that need to be considered during the transition to digital education. These categories cover the whole space of the DTs in education and they will ensure ILO-TLA-AT alignment.

4 Results

This work is based on practical experience in re-designing TLAs and ATs in a distance education environment. In particular, the *Scientific methodology* and the *Manufacturing processes* courses are analysed focusing on the TLAs and ATs designed to maintain the alignment with the ILOs. The analysis of the courses identifies the TIT categories and the corresponding sub-categories, namely the aspects of TLA and AT observed for each TIT category. In more details,

- *Technology category* includes the digital technologies involved in TLA and AT. These technologies are introduced to enhance the student learning experience in a distance environment and facilitate the achievement of the ILO. The technology becomes the mean to deliver the lecture, the laboratory or the assignments. The sub-categories identified are: Forum, Action cam, Video conferencing tools, Cloud-based tools, Digital white board, Learning management system.

- *Interaction category* considers the engagement of the learners in the online courses. The level of interaction between teacher-student or student-student, communication and participation, and community building are mainly investigated. Teachers and students needed time to adjust to distance learning, e.g., how to use and exploit the features of digital technologies to facilitate and enhance interaction. In more detail, these technologies created new ways of how interaction happens for both teachers-students and student-student (e.g., through a camera or a chat). The identified sub-categories are:

Table 3: The digital TLAs and ATs designed to ensure the alignment ILO-TLA-AT of the course *Scientific methodology*. The aspects of the digital TLAs and ATs are highlighted in bold and correspond to the sub-categories abstracted to the *Technology, Interaction and Time* (TIT) categories.

TLAs			**ATs**
Lecture/ Guest Seminar	Homework	Class work	Remote examination/ Essay Report/ Class presentation
– The **“screen sharing”** of **video conferencing tools** enables **equal visualization** for the students that follow the slides from their own **screen**. – Teachers and students connect to the lecture **right on time**. – **Live** lectures are **recorded** and published. The videos can be watched at any time and re-watched if something was not clear in the first place. – Use of digital **white board**. The computer screen becomes the new board for the teachers thanks to the touch screen technology. – Lack of **student´s feedback** during the lecture and **connection** with the teachers. The teachers cannot perceive as well as monitor the degree of attention, leading to lack of control.	– **Video conferencing tools** allow group work in a virtual setting. This needs more coordination among the group members. – **Collaborative tools** (e.g., google docs and presentation) for **co-creation** and **sharing**. – **Feedback** from peers on a slower pace. No physical interaction in class for quick update. There is no physical interaction in class for quick update.	– The **“breakout rooms”** of **video conferencing tools** splits the students in groups for discussion. This is a **synchronous** method useful during lecture to make students reflect in groups) – An **“online discussion”** is set on the **learning management system** as an **asynchronous** method for students to provide short reflections on a topic related to the lecture given. – A ”**one-minute paper**” [3] activity where students post their answer in the chat.	– The **Video conferencing tools** creates **virtual rooms** for monitoring students creating a virtual room for being in the exam. – Questions were open mic or posted on the **chat**. – **Learning management system** used to publish the exam tasks and to upload essays and reports. – New exam format to avoid cheating: a short initial **quiz** with multiple choice questions is proposed to the students; a series of open book questions are presented as essays.

[3] A one-minute paper is a common technique designed to get rapid feedback on whether the teacher´s main idea is correctly perceived by the students. In the basic format, students have 60 seconds to briefly write down on paper anonymous responses to provided questions that reflect a certain aspect of the today´s lecture. For instance, students may be asked to highlight the most important points learned during that lecture. The teacher collects the responses and assesses them.

Table 4: The digital TLAs and ATs designed to ensure alignment ILO-TLA-AT of the course *Manufacturing Processes*. Highlighted in bold are the aspects of the digital TLAs and ATs that correspond to the sub-categories abstracted to the *Technology, Interaction and Time* (TIT) categories. The average passing rate is 30-40 % at each test, about 50-70 students attend, consequently quiz is selected to reduce instructors' load and because it is very difficult prevent cheating in online essays and numerical tests.

TLAs			ATs
Lecture	Homework/ Consultation hours	Class work/ Practical lectures	Remote examination/ Report/ Class presentation
– **Video conferencing tools** causes the **lack of student's feedback** and connection with the teachers that cannot control them easily. – **Pre-recorded video** allows students to **customize** the learning process and facilitate numerous activities in the use of the pc at home (visualization, hardware, software, power, etc). – Easy access at home to visualization, hardware, software, charge power, etc. – **Remote virtual laboratory**[4] using a simple **action cam** that allows a machining process customized experience **"remote piloting"**.	– **Video conferencing tools** trigger virtual consultation hours, overcoming logistics and time issues. The live consultation hours make logistics and time issues for students preventing them from taking the opportunity to discuss with the teachers. – Increased attendance and **opportunities** of **discussion** with the teacher.	– **Virtual team** for homework is a practical experience of project management in the context of remote working. It imposes the communication of the members as well as a formal definition of the task. – **Collaborative tools** become a standard in the current skills that a "smart worker" should satisfy.	– The high number of participants (100+) requires a **time-framed quiz**. The quiz generation is a **quite time consuming** for professors (but necessary) task. – The oral examination is divided into two sections: the **class work presentation** and the theoretical questions; a final report of the project work is uploaded to the **learning management system**.

[4] *https://www.youtube.com/channel/UCMOdP5P7Q4lbYDZ7x2Bow1g*

Feedback, Networking, Socialization, Level of student engagement, Level of interaction among peers and teacher-student, Live interaction with chat and with ”remote piloting”.

– *Time category* refers to how the time dedicated to teaching has been spent with asynchronous and live activities. It has been observed that time may be managed in a more flexible way with the digital version of the course due to the mix of asynchronous and live activities. Sub-categories identified are: Asynchronous and live activities, Time dedicated to teaching, Puncutuality.

5 Discussion

The analysis of the two courses has led to the same conclusions in all three categories. The following paragraphs summarise the most relevant observations.

– *Technology category*: digitalization has introduced new digital technologies in education that created new ways of how teaching and learning happen. Digital technologies have improved the student experience of teaching. In particular, the video-conferencing tool has specific features, such as screen sharing, that allow each student to follow the lecture and what the teacher displays from their screen. The combination of video-conferencing tools and action cams is used to stream practical laboratories. Therefore, the students can virtually attend the laboratory sessions that otherwise would not have been possible. The use of digital technologies has also brought a sense of equity in different ways. There is now equal visualization in the virtual classroom by connecting personal laptops to live lectures: the slides are more visible independently of where the student sits. Students do not have to share the limited IT resources available in the computer labs to perform their exercises with other students. Using their laptops allows each student to try out the activities themselves instead of passively following what other group mates do. Moreover, all the previously mentioned technologies highly impact the two remaining categories (cf., following two paragraphs). To conclude this overview, it is worth noting that the only identified drawback of these technology tools is that some disadvantaged students cannot use such power.

– *Interaction category*: communication and interaction between teacher-student and student-student are key challenges. Firstly, it is important to notice that digital technologies allow interaction to happen. In detail, the above mentioned technologies create the interaction platform and tools used by teachers and students. Secondly, virtual interaction has increased the attendees' anonymity (e.g., teachers see the students as black squares on the screen when using video conferencing tools). This anonymity is considered an advantage from the students' perspective (e.g., during consultation hours more students take the opportunities to listen to the discussion or clarify their doubts privately in the chat with peers). As another opportunity to increase the interaction, students are positive about forum-like activities, i.e., online discussion, set on the learning management system. Students can share their thoughts and discuss with others. As a drawback, student engagement during live lectures can drop. For instance, most of the students tend to listen passively to the lecture without asking questions and teachers find it challenging to monitor the degree of attention of the audience.

- *Time category*: the digital technologies allow deciding whether the activity in focus would be asynchronous or live, impacting time management. For instance, students can access the course content via pre-recorded video (asynchronous): lectures, seminars, and laboratories are available “on-demand”. This has increased flexibility in managing time. The learning process is now more independent of time. However, the educators dedicate more time and effort to teach due to a lack of experience in distance learning technologies. This results in stress and increased workload for the educators.

To conclude, this work has focused on two courses that are considered antithetical, meaning that they are characterised by dissimilar content. One course focused on how to perform, design, and document a research endeavor. The other one focused on how to design and optimize specific manufacturing processes and related parameters. The dissimilarity of the courses marked two ways of coping with the DT. However, the analysis has shown similar aspects in dealing with the DT that converged in the TIT categories. Future research may enrich and improve the current work by considering a broader set of courses. This further information may refine or extend the already identified TIT categories.

6 Conclusions

The CA introduces a feedback loop between *what* and *how* the teacher wants to teach. The resulting course design is more resilient and can successfully overcome unpredictable events such as the demand for online teaching.

However, the forced digitalization of education due to the above mentioned pandemic has challenged constructively aligned courses. Therefore, educators had to think about new ways of performing TLAs and ATs to preserve the ILO-TLA-AT alignment established before the digital shift.

This work proposes the TIT categories as the main relevant dimensions to consider in TLAs and ATs’ re-design process. The proposed categories must be considered as guidelines to be followed during the top-down exploration of different domains.

The abstraction process adopted in the methodology allows transposing specific engineering instances to a set of general variables that may be considered as a reference point also in different disciplines. However, further research and additional case studies are needed to validate the proposed categories.

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