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Assessing the Impact of Communication Instructional Tools and Strategies on the Students' Learning in the Context of Blended and Online Methodologies*

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In the last fifteen years communication paradigms have radically changed. From relations mostly based on synchronous and face-to-face conversations, to formal emails and phone calls and, today, videoconferences and different asynchronous chat mobile applications. This change has also affected higher education, where many innovative strategies and instructional tools enabling communication among students and with professors, have been implemented. The final objective of all these mechanisms is to increase the impact of the tutorial action, thanks to a fast and continuous interaction with professors and the collaborative learning among students. However, informal observations seem to show that some tools and/or strategies are more successful than others, depending on the teaching and learning methodology. Therefore, this paper aims to study the impact of different communication tools and strategies in the higher education students' learning, including academic results, motivation competence acquisition level. We are focusing on blended and online methodologies, as they are implemented in most current engineering degrees. The study considers five subjects analyzed during three different courses. Four different communication instructional tools were also studied, including forums, emails, Telegram and Discord. Besides, four different communication strategies were also considered. Results were evaluated using statistical methods. Results show the improvement in the students' learning is especially relevant when chat applications and immediate responses are provided in the context of online teaching methodologies. In blended methodologies, on the other hand, chat applications are clearly preferred too, although improvement may be achieved with almost any tool.

Keywords: communication tools; communication strategies; engineering education; blended methodologies; online methodologies

1. Introduction

The successive technological and social revolutions suffered in the last forty years have totally changed the way people communicate and, even, live [4]. From a society primarily based on face-to-face synchronous conversations, and some other costly and slow communication methods (such as physical advertisements or traditional mail), we have evolved to a scenario clearly dominated by digital services [22]. While the old traditional methods introduced large latencies, so the communication process had to be designed to be very effective and take place at the optimum moment; the new digital services are characterized by a very reduced cost (even a part of the population feels they are for free) and their immediacy and total availability. These characteristics have increased the Quality of Experience of users but have penalized other communication methods such as email or phone calls, that are transition tools between the most traditional and the current digital situation. Today, most of these mechanisms are restricted to formal and professional communications, and although the 2020 COVID19 pandemic strongly promoted the use of videocalls [7], this impact appears to be transitory.

This change has also affected higher education, but in a more relevant way considering the nature of communication among students and between professors and students. Although some tools are being replaced by others with higher efficiency and lower cost is part of the communication evolution; the transition to innovative digital services is disturbing the traditional structure of communication in higher education scenarios [30]. In higher education, communication flows are sparse, very clear, and high-quality. Official sources (such as professors or delegated students) are not very numerous and act as authorized voices in their context. On the other hand, digital services promote a worldwide connection, where all actors have the same relevance. Thus, information flows are continuous, very numerous, difficult to manage, typically ineffective, and, many times, low-quality. The propagation of fake news or rumors is very difficult to prevent, and the caused disinformation situation very difficult to reverse [15].

However, the use of these new digital instructional services in higher education is increasing.

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Even, for some tools, their use is completely massive [6]. Tools such as chat mobile applications (Telegram, WhatsApp, etc.) have replaced other very popular instruments in the past, such as emails or physical advertisements, in the students' lives. Thus, tutorial actions based on synchronous meetings, emails, etc. do not satisfy the expectations of students, and they consume other non-official sources [5]. To improve this situation and support continuous and fast interaction between professors and students (and between students), the tutorial action has also incorporated instructional tools such as Telegram or social networks [14]. The final objective is to present the authorized voices, fighting against fake information. Nevertheless, the use of these instructional tools also causes a collision between the professional and personal planes, a situation that is not well tolerated by all students. In addition, professors and students, often, cannot communicate efficiently their messages, as the number of information flows is numerous, and they do not have any privileged situation among this avalanche of data. In this context, some institutions are more conservative and only allow students and professors to interact through formal mechanisms such as private and moderated forums, email or official communication platforms. However, this option does not solve the problem, as the tutorial action gets degraded, and students create parallel communities where the professor is absent, and the information is low-quality.

On the other hand, the use of any of these instructional tools requires a clear strategy. As the number of students to be managed increases, the tutorial action may turn into a very costly activity, which may not be performed by the professors. Although some institutions have created special offices for this task [21], in other cases professors must define a strategy that controls the impact of the tutorial action on their schedule. However, the final results of the global teaching methodologies are not agnostic to the implementation of these communication strategies and tools and the performance of the tutorial action. Especially in those cases where blended and on-line methodologies are employed (which is the most common case in engineering education). Therefore, a very complex balance must be found for every particular scenario.

In general, informal and qualitative observations show a variable behavior and results depending on how the tools, communications strategies, and global methodologies are combined. However, a deeper and more formal analysis is needed before reaching any conclusion.

Therefore, in this paper, we describe several different, but complementary, experiences focused on analyzing how the use of the various communication tools and strategies impact in the global performance of blended and online teaching methodologies. During several consecutive courses, four different communication tools were studied, including forums, emails, Telegram, and Discord. Additionally, four communication strategies were also considered. Five subjects using various blended and online methodologies were analyzed from 2018 to 2020. Different degrees in the computer sciences and engineering area were considered.

The rest of the paper is organized as follows. Section 2 describes the state of the art in communication tools and strategies in Higher Education and the related reported experiences; Section 3 describes technically how the different tools and strategies work and how they were employed by students and professors. Section 4 describes the experimental methodology, the context of the proposed experience, and the experimental results. Section 5 concludes the paper.

2. State of the Art on Communication Tools and Strategies. Reported Experiences

The fast evolution of communication paradigms and the incredible transformation of society caused by these changes have made research on communication tools and higher (and engineering) education very popular in the last twenty years. However, traditional works on how asynchronous communication instructional tools can be integrated in engineering education [17] and how they impact the performance of students [37], transformed in the last ten years in practical reports on educational experiences based on specific communication tools [18]. From web 2.0 and social network ecosystems at the beginning [33], to current experiences based on intelligent environments [1] and corporate team tools (such as Slack) [26]. Nevertheless, all these experiences are usually based on observations for a limited amount of time (some weeks) and pilot groups where only a few students are integrated [29]. In general, larger studies are needed to extract more solid and deeper conclusions. Despite this fact, the state-of-the-art includes several works on how to improve tutorial action in higher education through innovative communications tools.

One of the most studied instructional tools are social networks. Probably the first social network used as communication and educational tool was Facebook [16]. In general, reported experiences about Facebook and engineering education employ Facebook groups as a Learning Management System (LMS) [38]. However, most of these experiences are limited to the Anglo-Saxon world

(USA and UK) [10], where students are more familiar with this tool than in Europe or other regions. Thus, the validity of the reported results in other contexts is not confirmed. The results show as the main advantage the possibility of managing and communicating with large communities (more than 200 students) in a very easy manner [11]. However, the benefits for students are much less clear. On the one hand, it is a complex tool and some discrimination situations happen against students who are not users of this social network and who present more difficulties in communicating [25]. However, students are worried about their privacy, as all personal information is available in these kinds of Facebook groups [9]. In fact, due to these unsolved problems, experiences with Facebook indicate a declining trend over time [10].

Another very popular social network to be used as communication tool in higher education is Twitter. In this case, experiences in different geographical areas have been reported, from Europe to the United States [35]. However, the results show a clear dependency on the cultural and geographical context [13], and while American students understand Twitter as a professional tool, Spanish students feel it as an entertainment environment [35]. Furthermore, messages on Twitter are searched and classified in a very difficult way, so students tend to consume personal, media, and educational resources together, what penalizes their learning [13]. Finally, some privacy-related problems reported within Facebook experiences are still present in Twitter (as well as in most social networks), so the use of Twitter in engineering education also seems to decline [32]. Actually, although some experiences based on more modern social networks, such as Instagram [3] or TikTok [12], have recently been reported, they are very sparse. Only in artistic disciplines, where those platforms are relevant tools to share media content, their use seems to be effective [12]. In any case, most of the reported experiences are very limited, and they consider a reduced number of participants and a short duration. Furthermore, most relevant community movements involving post-teenagers, such as Discord servers or Twitch have not been analyzed.

Classic communication instructional technologies such as email have also been studied in great detail. In general, email is perceived as a more distant and impersonal communication channel, so studies on how this technology impact in the students' motivation and the effectiveness of messages are common [36]. In general, the results show that students feel more motivated when they can interact synchronously with professors. To address this problem, chatbot-based tools have been implemented in engineering courses [8], but although the immediacy satisfies students, the quality of interactions is poor. On the other hand, communication strategies related to email and tutorial action have also been investigated [2]. Specifically, the impact of "silence periods" on the learning process is analyzed [2], showing that they can promote the autonomous learning. As an evolution of these instructional tools, corporate ecosystems such as Slack have been studied as communication tools in higher education courses [26]. The results show that these innovative tools are more valued than email by students [19], but it is not clear whether this improvement causes better learning or if it is more relevant than the improvements achieved by other tools and strategies. In addition, experiences are very limited to extract relevant conclusions. On the other hand, mobile chat applications (as natural evolution of email solutions) have barely been analyzed. Only a few very recent works address the use of Telegram or WhatsApp in higher education [31], without relevant conclusions and with very limited validity as they are focused on pandemic and lockdown situations.

Finally, different ad hoc instructional communication tools and strategies have been implemented in higher education courses and reported experiences. However, the results tend to be qualitative [34], and more focused on identifying trends and challenges [20] than evaluating the improvement in student learning. Other works identify procedures for implementing new ICT (information and communication technologies) into higher education contexts [23]. However, in general, new quantitative studies considering longer analysis periods and comparative experiments among different tools and strategies are required. This work fills this gap.

3. Proposed Communication Instructional Tools and Strategies

In order to improve the quality of the tutorial actions in engineering courses, different communication instructional tools and strategies may be employed. In this research, we are considering four different tools: forums, emails, Telegram, and Discord. All these instructional tools cover a large catalogue of communication paradigms, including synchronous video calls, direct (or personal) chat conversations, generic public advertisements, group or collaborative discussions, and formal messages, among others. On the other hand, all these tools can be managed following different strategies. In this experience, four different communication strategies were implemented and evaluated. Namely: immediate response, best effort, periodic interactions, responses as the last option.

These strategies range from full availability and dedication to the tutorial action, to mechanisms based on everybody doing its best, and schemes where professors only communicate if it is absolutely essential. Different subsections describe each tool and strategy. All of these instruments have been integrated into a more general blended or online learning methodology (the most common in engineering courses) described in Section 4.

3.1 Communication Instructional Tools: Technical Description

Although many different communication instructional tools, with several capabilities and technological support, are available for higher education professors and courses, in this work we are focusing on those tools with a large presence in civil and general society. Application-specific solutions are not addressed in this experience, as they are difficult to implement in various contexts, subjects, and institutions. This research aims to provide a long-term, transversal study of communication tools and strategies in engineering education, so tools with long-term support and a technical maintenance policy are essential. In this context, commercial or corporate instructional instruments meet these requirements. In addition, no student should be excluded because of technical or economic issues. Thus, all employed tools must be multi-platform, so students can employ them using laptops, smartphones, or any other infrastructure they have.

The present knowledge of online and blended methodologies clearly indicates that the instructional tools employed, to be efficient, must allow students to acquire concrete and abstract learning and competencies [48]. Dale's cone of experience [47] describes the activities to be enabled by effective instructional tools. But, depending on the teaching methodology, some of these activities may be organized through other tools or in person. And students feel more engaged by tools that are easier to use, with no duplicated functionalities [50]. On the other hand, tools based on remote instruction tend to make students feel disconnected. And most recent theories about online learning show that a synchronous component is always required [49]. Activities that can be performed with each tool, and the way in which they could be organized, must be carefully analyzed to identify the instruments that would improve the students' learning and under what circumstances.

Four different instructional tools were considered in this experience: forums, emails, Telegram, and Discord. While forums and email are provided and supported by higher education institutions as a corporate resource, Telegram and Discord are popular commercial technologies with great penetration among young people. Telegram is a mobile chat application and Discord is a web 2.0 tool similar to an enhanced social network.

3.1.1 Moodle Forums

All higher education institutions that participate in this experience implement Moodle as a corporate Learning Management System (LMS). On this platform, all subjects, professors, and students are provided with a private space where all resources related to the course are available, including study material, evaluation activities, administrative information, etc. The referred space is managed by professors, although the global Moodle platform is maintained by the IT (information technologies) services from each institution. Different universities may customize the Moodle platform in a different way, as it is an open source, free solution. However, despite the different front-end or user interface, all Moodle platforms considered in this experience have the same functionalities.

In general, Moodle offers a catalogue of capabilities or resources, which professors may integrate in the private space dedicated to every course, and where professors and students interact together and among them. One of these resources is a forum.

A Moodle forum is a public space where all students and professors can post messages, creating hierarchical conversations. Communication is totally asynchronous. All participants may open new conversations, which are displayed in chronological order as a FILO (First in, Last out) stack, i.e. oldest conversation as displayed at the bottom, while most recent topics are placed at the top. The title or name of each conversation typically specifies the topic addressed in the conversation, although there is no instrument available to control or ensure that it is available. It depends on the behavior and commitment.

Moodle forum can be read and edited through a web interface or the Moodle mobile application, as can be seen in Fig. 1a. In addition, in this figure the different options to customize the messages are shown. In general, all HTML labels are available, including bold, italic, different font sizes, embedded images into the text, different text alignments, etc. This can help users to highlight some ideas, create quite long responses that are readable.

Although sometimes new messages in Moodle forums may be notified through an email message to all users, in our experience, we are not considering this functionality, as email technologies are studied in a separate experiment. To help students and professors to learn when a new message has been published, in the right lateral menu, a list with the new responses and conversations since the last connection to the Moodle platform is shown. How-

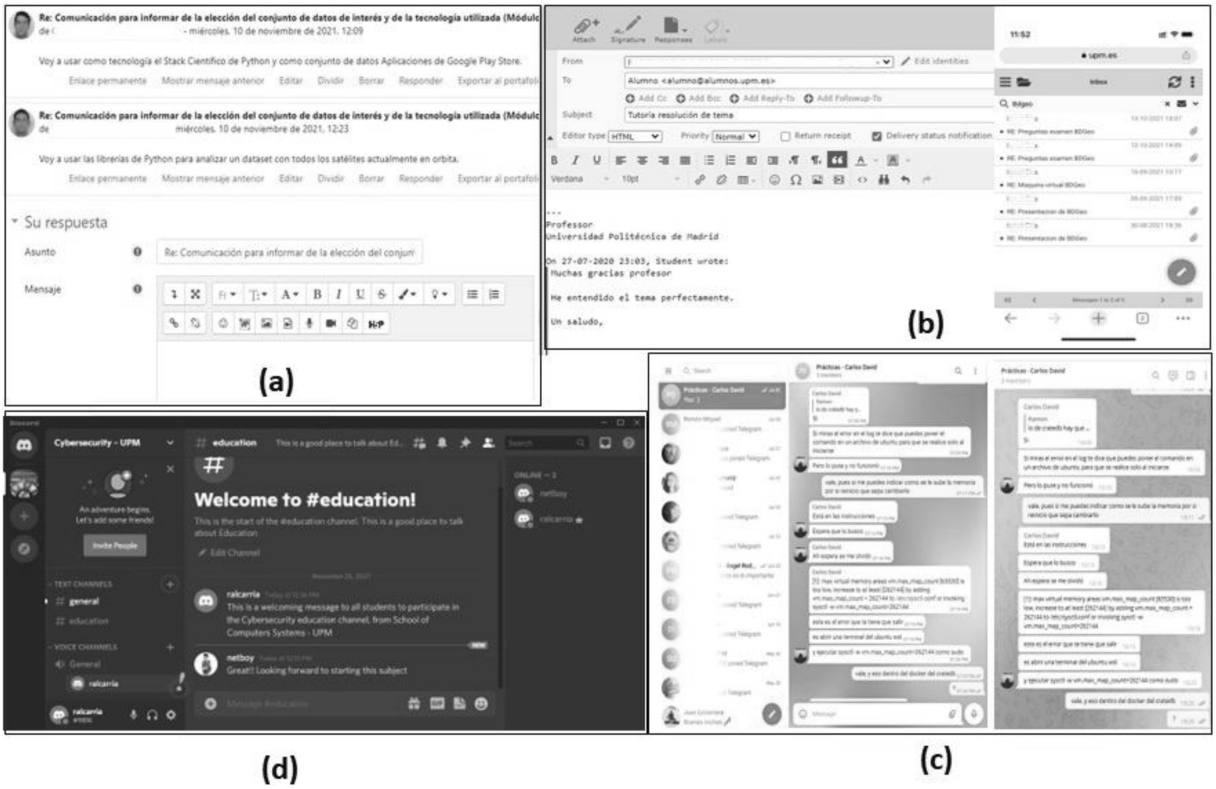

Fig. 1. (a) Moodle forum as implemented in the proposed experience (b) Webmail as provided and employed in this experience (c) Telegram web (left) and desktop (right) interfaces (d) Discord basic interface.

ever, nobody receives a confirmation when its messages are read.

In addition, messages may be edited by authors at any time. Typically, for the first fifteen minutes, any new message is blocked, just in case the author decides to make any change before publication. After that time, messages are published, and all users may see the original message and all future updates.

Moodle and other LMS would facilitate and improve the students' learning as they present content in a structured manner, so Moodle forums can be easily used as knowledge repository and abstract activities in the top of the Dale's cone (such as view images or read) are enabled. However, knowledge retention is higher if collaborative lessons are allowed, too [51], and young students feel that additional collaboration functionalities are needed on Moodle forums [52]. The final enhancement in the students' learning would depend on how the teaching methodology provides additional instruments and opportunities for peer-to-peer collaboration.

3.1.2 Corporate Email

Together with Moodle as a corporate LMS, all universities involved in this study provide students and professors with a corporate email. This email, in fact, is the official method to communicate with people (specifically professors). In this context, all professors are provided with an online space where their official contact information is displayed. Although this information also includes a land telephone number, in this experiment we are not considering this technology, as it is clearly unused. Professor may be located through a specific browser. Furthermore, this information is also displayed on different websites (such as the Department's page), but no official support or guarantees for long-term maintenance are provided. As is well known, email is an asynchronous communication method.

The official email system is technically supported by servers hosted by universities and accessed through a webmail interface. Although all these accounts may be integrated in different email clients and messages may be forwarded to other accounts (such as a Google account), in this experience we are only using the official webmail system, as it is the only one with universal access for all participants. The webmail system has two different visualizations (see Fig. 1b): desktop and mobile device; although no native mobile application is provided in this case, only web connections are allowed.

The webmail application and email system manage messages in two formats: plane text and

HTML pages. If HTML pages are selected in the drop-down menu (see Fig. 2), a new contextual menu appears with all traditional functions: text alignment, bold font, images to be embedded, etc. In addition, in this case, users may select two options that can be selected by users: return receipt and delivery status notification. If return receipt option is activated, when email is opened by the receptor, a pop-up window allows him to send a message to the sender, confirming the email has been read. However, the receptor may deny his permission, and no confirmation message is sent. On the other hand, the system when the message is delivered to the receptor account. However, no information about if the user has opened or read the message.

Although other email solutions give a time to recover the email before it is definitely sent, this functionality is not available in these corporate emails. Any rectification needs a second message to be sent. Finally, this corporate email system allows sending attached files (all formats are allowed) up to 25MB in each message.

From a logistic point of view, although students can easily locate the professor's email address, it is quite complicated for professors to learn about the students' addresses. No repository is provided, and professors must manage to get all addresses from all their students if they want to use this communication tool. Besides, distribution lists and other similar instruments making easier the communication process must be also maintained by professors.

These logistics limitations make collaborative work very difficult via email. And then, this instructional tool is not generally used as the primary learning vehicle but as a way to empathize with some key information or topics [53]. However, for courses where competencies and experiences in the middle levels of the Dale's cone (such as writing) are the main component, the email would help students to improve their learning and feel more engaged and developed [54] as this instruction tool is specifically designed for these activities. Some cultural issues related to formal communications may arise and decrease the students' learning [55], but we have not detected this problem in our educational context.

3.1.3 Telegram

Telegram is a mobile chat application, one of the most popular in the world. Telegram messenger is an application for instant messages, file sharing, and massive communications. Although Telegram is integrating other functions such as bank transfers or cryptocurrencies, in this experience we are only employing and focusing on the communication options. Messages in the Telegram are stored in cloud, although they can be hidden if desired. Any message may be configured to be forwarded or removed after a certain time. In addition, by using a search tool, any user may go through all their messages. Additionally, videocalls are also supported, face-to-face, or in a group.

Different communication options are available on Telegram. From traditional chats where all users may intervene and publish messages, to diffusion channels where only some authorized people may publish relevant news and announcements. In addition, Telegram supports bulletins and voice chats (for those people with writing or reading difficulties, such as blind students). There are no limits to the number of participants in any chat. Furthermore, privacy configurations are independent for each communication channel. In this context, a very relevant functionality to address student privacy worries is the possibility of defining an alias. An alias is something similar to a username in Telegram that enables people to look for people without sharing the personal phone number, just through the alias. On the other hand, students may show their profile photo only to some contacts, so their privacy is completely preserved.

All chats and diffusion channels are asynchronous, although synchronous video calls are also available. During this experiment, professors could employ this functionality if they wanted, but students couldn't. Additionally, professors can create surveys for participants in any chat or diffusion channel. Students could only respond to the surveys proposed by the professors.

Although Telegram is a native mobile application, there is also a web version and a Desktop application, as shown in Fig. 1c. All participants are free to choose the Telegram client that best fits their needs. In any case, all clients offer the same functionality. Messages do not have format, and only plane text is allowed. Although images and other files can be shared, it is not easy to create complex text structures in Telegram (with alignment, images, etc.). On the other hand, files up to 2GB may be shared (all formats are allowed).

On the other hand, senders are notified when their messages are received and read through a simple and a double check, placed together to the message. Although users could turn off this functionality, professors kept it activated during the experience. When there are more than two users in the chat, you can see the individual information for each participant. Also, messages can be removed, but not edited. Although Telegram offers the ability to edit any message where you are the author, this option actually sends a new message.

In a more technical approach, Telegram uses the Mobile Transport Protocol [27] to manage,

encrypt, and transport messages, contacts, and metadata. It was specifically designed and developed for Telegram, although it is an open standard based on Java technologies. Thanks to this new protocol, messages in Telegram are end-to-end encrypted, identifiers are independent from the IMEI (International Mobile Equipment Identity) number (associated to specific devices), and files of any size and format may be transported.

From a logistic point of view, professors may distribute an invitation link among students (for example, writing it down on the blackboard the first day), so there is no need to collect individual data from students (which makes easier to manage large groups of people).

Telegram would significantly increase the students' learning thanks to its focus on collaboration. Nowadays, Telegram has become an innovative but very popular instructional tool to increase the peer-to-peer interactions in online and blended methodologies [56], so students do not feel disconnected. In general, students accept Telegram as an official instruction tool easily [57]. And it increases its engagement, as Telegram facilitates mobile learning and the ubiquitous presence of educational content and activities [58]. However, this tool presents some problems related to the writing communication and related experiences in the Dale's cone. Existing knowledge confirms some students Telegram is an instructional communication tool and get distracted or informal, affecting the learning of the entire class [59]. The teaching methodologies should be aware of this problem and deploy countermeasures.

3.1.4 Discord

Discord is a freeware messaging service, including voice chats, text chats and videocalls. Although it was designed as a platform for the videogame community, it is a general-purpose solution. It is one of the most popular communication tools among young people, including college students. Currently, Discord servers (as they are named the Discord communities) have separated channels for voice calls (synchronous communications) and text chats (unsynchronous communications). Of any channel type, an unlimited number of those may be created. Discord also allows sharing the screen and/or a video stream in real time. Thus, different conversations may take place at the same time without any conflict. Besides, any user may select the conversation he wants to participate in at any time and dynamically.

Discord functionalities are simple but very configurable (see Fig. 4). Privacy is totally preserved as no personal information is shared, just a username (common to all servers where the user is involved). Messages on text channels in Discord cannot be edited or removed, but files of any format may be shared. Also, messages can be fixed, so they appear at the top of the channel and in the top menu, as shown in Fig. 4. This functionality is useful for relevant information, as chats tend to accumulate a huge number of messages as time passes. On the other hand, the channel can be silenced, and different threats can be defined within a text channel, such as #education in Fig. 1d.

Two clients may be employed to connect to Discord servers: web interface or a desktop application. In both cases, at the technical level, web technologies (JavaScript) are employed as a programming language. Although when using the web interface native technologies are employed, desktop applications need the Electron framework to develop graphic interfaces in executable applications using web solutions such as Node.js and Chromium. The system shows good Quality-of-Service thanks to a solution such as Opus codec (audio data format), characterized by a very reduced latency.

In general, Discord is a free service and open-source software, although some functionalities (known as Discord Nitro) require payment. In this experience, these functionalities are not considered. Among the free functionalities, one of the most used ones is the intelligent searcher, making it possible to navigate through the messages in the text channels. Using commands, different search options and criteria may be selected: time periods, type of content, etc.

Through the lateral menu, the list of users in the server and their state (connected, absent, etc.) may be seen. However, there is no confirmation that any user has read or not by any user. Messages have no format (just plain text), although images can be embedded in messages.

Identically to the Telegram chats, from a logistic point of view, professors may distribute a Discord invitation link among, so there is no need to collect individual information. This makes Discord solution much more efficient than email, for example.

Discord is the instructional tool that achieves the most significant student engagement. As Discord allows students to not only write messages, but also voice channels and video streaming, they feel more engaged and connected thanks to this synchronous component [60]. Using Discord, all activities in the Dale's cone can be performed, so students' learning would improve significantly. Collaborative knowledge exchange would also improve according to existing evidence [61]. In addition, students adopt Discord as an instructional tool very easily and quickly create learning communities [62]. But this is the main disadvantage of Discord. For students

Table 1. Context description for the different subjects

Tool	Moodle forum (LMS)	Corporative email	Telegram	Discord
Tool owner	University	University	Private company	Private company
Technical functionalities	Only written messages. Enriched text. Messages in a FILO list.	Only written messages. Enriched text.	Encrypted chats. Voice and written messages. Image and file sharing.	Text and voice channel Video streaming and file sharing
Logistics	Managed by University IT staff. All students are registered by default.	There is not a general distribution lists containing all students.	An anonymous invitation link can be massively shared.	An anonymous invitation link can be massively shared
Advantages for students' learning	Activities related to reading and data repositories are improved.	Formal writing is enhanced, and key information easily highlighted.	Collaboration is promoted. Facilitates the mobile learning and the students' connectivity.	Students' engagement is promoted. Learning communities are established.
Disadvantages for students' learning	Collaborative lessons difficult to implement.	Collaborative lessons difficult to implement. Sounds, images, etc. are difficult to share.	Students get easily distracted and informal.	Requires a large synchronous and permanent activity.

with an episodic participation, Discord is not easy to adopt, as it requires a synchronous and permanent participation. Depending on the specific teaching methodology and how it mitigates the flaws of Discord, the advantages or disadvantages would be more relevant.

Finally, Table 1 shows a comparative study of all the proposed instructional communication tools.

3.2 Communication Strategies

In general, communication behavior is independent of the selected communication tool, although some tools are designed and promote certain attitudes more than others. Any communication strategy depends on several variables, such as the use of language, figures, colors, and formats (when written communications are involved), or the scenario and camera configuration in videocalls, among other things. However, in the higher education context, most of these variables cannot be controlled: a very technical language is mandatory, infrastructure is usually configured and managed by specialists, not by professors (who are just users of these systems), and other materials such as figures, or colors, are not available in all contexts or subjects.

In that way, the main variable that defines the communication strategy in higher education is the response time, or the response strategy. Although almost an infinite number of different strategies may be configured only considering the response time, the state of the art has typically considered four possibilities, ranging from the shortest response time to the longest values. In general, these strategies are considered exhaustive and enough to evaluate and represent all possible situations. These strategies are immediate response, best effort, periodic interactions, responses as last option.

3.2.1 Immediate Response

Ideally, with this strategy, professors would be fully available to respond to students' messages, calls, etc. The response time will be negligible, and the professors' intervention will be very strong. No response from any other user would be faster, so all questions will have an immediate and official answer. From a theoretical point of view, this strong presence of official information will reduce the risk of rumors or false information. However, this ideal implementation is almost impossible to reach, as rarely is a full team of people available to monitor communication channels 24 hours every day, seven days a week. And in asynchronous communications, no one has control about when a message will be received.

Thus, in practice, this strategy was implemented in the following way. Two time periods were defined within each day. From 8am to 9pm (local time), the professors ensured a response time below thirty (30) minutes. At any other hour (from 12am to 8am and from 9pm to 12am), no response will be sent until 8am (the next day). These periods coincide with the university schedule, when the buildings are open, and classes are running. So, students are used to it and includes 90% of study time (when they tend to use the communication channels and the tutorial resources). Regarding the maximum response time (thirty minutes), it was established considering the average duration of professors' meetings, classes, and similar obligations. Thus, it is a value that may be assumed by all professors. In the same way,

professors were only available five days a week (Monday to Friday). During the weekend, no response was sent until next Monday at 8am.

As a disadvantage, with this practical implementation, a higher risk associated to rumors and fake information is generated.

3.2.2 Best Effort

In the best-effort communication strategy, professors have the responsibility to answer messages and calls as soon as they can. In this case, no specific criteria or maximum response time is specified, but all professors must do their best to response in the minimum possible time. In general, this is the strategy used by most professors in their professional life by default. This scheme, depending on how each professor schedules its work, may also consider weekends and/or the nighttime as an available period for answering questions and communicating with students. However, in order to guarantee that the different strategies are comparable, and the experience does not depend on the professors' schedule, we define some mandatory rules.

As in the previous strategy, two time periods were defined within each day. From 8am to 9pm (local time), professors will do their best to answer questions and communicate with students as soon as possible. At any other hour (from 12am to 8am and from 9pm to 12am), no response will be sent until 8am (the next day). An identical reasoning to the one proposed by the "immediate response" strategy supports these decisions. In the same way, professors were only available five days a week (Monday to Friday). During the weekend, no response was sent until next Monday at 8am.

In addition, regarding synchronous videocalls, professors will answer only one call each time. Once a videoconference has started, no more students are allowed unless they were initially invited, and they were just delayed. If any other student needs to communicate with the professors in a synchronous way, he must wait until the previous call has finished. Eventually, professors may schedule the call at a different time if that the best they can do.

3.2.3 Periodic Interactions

This approach is the most traditional one, as it is the basic communication strategy for tutorial action when no technological tools are employed, and in-person meetings are the only way to interact with other students and professors.

In this strategy, professors define a time slot when they'll be available for students and tutorial actions are open. In that way, during this slot it will be possible to communicate with the professors synchronously, and all asynchronous messages will be also answered. In general, this time slot is not unique and follows a certain periodic pattern (one hour every week, thirty minutes every day, etc.). Actually, most universities require professors to define this periodic slot for those students that desire to meet face-to-face with professors in their offices. According to regulations proposed by all universities considered in this study, this time slot must be a two-hours slot every two days.

Therefore, the "periodic interactions" communication strategy during this experience was implemented in the following manner. Professors freely defined a time slot of two hours on Mondays, Wednesdays, and Fridays, when they were available for synchronous calls, and when they were answering asynchronous messages. No calls or messages were received in any other time period. This schedule was repeated periodically every week. The specific time slot dedicated to the tutorial actions for each professor was published on the corporate webpage of each university. In this way, students were aware of periods when it is possible to interact with professors.

Only messages that have not been previously and correctly answered by a student or professor have been replied to. In addition, the professor will only answer messages during the scheduled time slot. If more messages are pending, they will be answered during the next time slot focused on the tutorial action. In general, messages are answered following a FIFO (First-in, First-out) scheme, so older unanswered messages are responded to first.

3.2.4 Responses as Last Option

This strategy is supported by paradigms such as peer-to-peer collaboration, the collaborative learning, and autonomous learning in engineering education. With this strategy, students are promoted to look for their own responses and help other students with their knowledge, as professors are only intervening and interacting with students if (after a certain time) they are not getting the correct answer.

In that way, every message does not receive an immediate response for professors, and only if after ten days the original message is still and answered, or if proposed answered and incomplete or incorrect, the professor publishes an official response. As a main disadvantage, this communication strategy is easy to implement with asynchronous textual channels, but synchronous communications are hard to integrate. The solution we defined was as follows: Students, before communicating synchronously with professors, had to leave a message asking for a call and the reason why they needed it. If after ten days they still need the call, it takes place. During the call, only the previously reported could be addressed. As in other strategies described

strategies, during the weekend no response was sent until the next Monday at 8am.

In general, with this strategy, although students are promoted to look for their own answers, the influence in weak and official messages may not get the required attention. In this way, the risk of rumors and false information is higher than in other strategies.

4. Experimental Results and Discussion

The proposed tools and strategies were implemented and deployed in five subjects belonging to two different higher education institutions (Universidad Politécnica de Madrid -UPM, hereinafter- and Universidad Alfonso X el Sabio -UAX hereinafter-). Those subjects belonged to three different engineering programs: Computer Engineering, Information Technologies engineering, and Software Engineering. In this section we are describing the context of this experience, and presenting the results obtained for the last four years (2018–2021).

4.1 Context

The proposed experiment was developed on five different subjects. The first one, ''Digital Systems'' (DS, hereinafter), belongs to the Information Technologies engineering at the UAX. It is a mandatory subject scheduled in the first course (second term). The second one, ''Computer architecture'' (CA, hereinafter), and the third one, ''Object-oriented development'' (OOD, hereinafter), also belongs to the Information Technologies engineering at the UAX, but in this case they are scheduled in the second course (second term). The fourth subject, ''Cybersecurity'' (CS, hereinafter), belongs to the Computer Engineering degree at UPM. This subject is scheduled in the third course (second term). Finally, the fifth subject, ''Geoinformatics'' (GI, hereinafter), belong to the Software Development program (MSc level) at UPM. This last subject is scheduled at the first course (first term). All subjects are mandatory in the programs under study. The experience ran for four years, from 2018 to 2021.

Teaching methodology was different in every subject.

DS, CA and OOD followed a fully online methodology. These subjects are organized as synchronous theoretical sessions. These sessions had a duration of one hour per week and they were based on professors' notes and practical exercises that must be solved by the student in their own. Laboratory sessions or other similar in-person activities were not considered. All materials and synchronous sessions were hosted in the institutional Learning Management System (LMS) based on the Moodle platform. Evaluation tests were carried out in person on university premises.

On the other hand, CS followed a blended methodology. The subject was organized as theorical sessions based on online professors' notes. These sessions had a duration of two hours per week. On the other hand, (in-person) software and embedded systems laboratory sessions were also organized every week. These sessions had a duration of two additional hours per week. Besides, all materials were publicly distributed among students through the institutional Learning Management System (LMS) based on the Moodle platform.

Finally, GI also followed a bended teaching methodology, but with a different approach. One in-person session per week with a duration of two hours was organized. Sessions had a practical approach, where 70% of time was invested into real developments. Theorical presentation were done in the remaining time. Professors' notes were available through the institutional Learning Management System (LMS) based on the Moodle platform.

Table 2 describes the subjects' organization, including the number of students each year, the units considered in each subject, and the usual schedule. To anonymize results and not contaminate the experience with pre-existing ideas, during all the experimental phase we label subjects as ''Subject A'', ''Subject B'', etc. Labels were resolved at very end of the experience when conclusions and analysis were finished and written.

The final objective of the experiments conducted is to answer some questions regarding the effectiveness of the different communication tools and strategies, in terms of student motivation, learning level and acquisition of competencies. Three research questions were formulated:

- RQ#1: Do the implemented instructional communication tools and strategies enable students to improve their academic results?
- RQ#2: Does the use of the proposed instructional communication tools and strategies enhance the students' motivation?
- RQ#3: Does the use of the proposed instructional communication tools and strategies enable students to acquire the required technical and/or general competencies?

4.2 Method and Participants

The validation described in this paper was planned, guided, monitored, and evaluated by its authors (hereafter *experts*), who have more than five years of experience in knowledge management, communication software and tools and data analysis.

Each subject was considered an independent group. Groups in years 2019–2021 were pilot

Table 2. Context description for the different subjects

DS							
Year	Number of students	Contents. Number of sessions					
		Boole algebra	Karnaugh maps	Combinational circuits	Sequential circuits	FPGA	Introduction to computers
2019	12	2	3	3	4	2	2
2020	15	2	4	4	4	1	1
2021	21	2	3	4	5	1	1
CA							
Year	Number of students	Contents. Number of sessions					
		Information coding	Introduction to computers	Instructions	Hardware implementa-tion	Control units	Memory management
2019	11	2	2	2	4	4	2
2020	13	2	1	3	4	4	2
2021	16	1	1	3	5	5	1
OOD							
Year	Number of students	Contents. Number of sessions					
		Encapsulation	Composition	Inheritance	Interfaces	Generics	Exceptions
2019	12	2	3	3	3	3	2
2020	16	2	3	3	3	3	2
2021	23	1	3	4	3	3	2
CS							
Year	Number of students	Contents. Number of sessions					
		Cryptography	Firewall	Operating systems	Hacking	Mobile devices	Wireless networks
2019	73	8	8	4	4	4	4
2020	87	4	4	6	6	6	6
2021	124	5	5	6	6	5	5
GI							
Year	Number of students	Contents. Number of sessions					
		Sensors	GPS	Location-based services	Mobile maps	Cloud computing	Mobile databases
2019	7	2	3	4	3	2	2
2020	5	2	3	4	3	2	2
2021	11	2	3	4	3	2	2

groups, employed to analyze the performance of the different communication tools and strategies and answer the research questions. Groups in year 2018 was considered as control group. All groups were configured to maintain homogeneity, make results comparable and increase the statistical relevance. The groups organization process performed by experts considered different profiles, with various technical skills and experience levels. Groups were configured considering the principles of gender equality. It was guaranteed that all groups were composed of comparable populations. Table 3 shows the characteristics of pilot groups for each year and subject.

All participants were treated anonymously by experts. No personal data related to the identification was stored or distributed outside the official platforms. All experiments were performed under the conditions of respect for individual rights and ethical principles that govern research involving humans.

The experience was conducted as follows. In each subject, for all the years under study, each thematic unit was tutored using a different combination of communication tools and communication strategies. Not all possible combinations of communication tools and strategies were analyzed. Some of them, as said in Section 3, were not technologically feasible. The proposed experiment considered the following combinations:

- First units (U1) in all subjects were tutored through an online forum with a ''response as last option'' communication strategy.
- The second units (U2) were tutored also using forums, but with a best effort communication policy.
- The third unit (U3) for all subjects was tutored through the email with a best effort communication policy.
- The fourth unit (U4) was managed with an immediate response strategy through the Telegram chat tool.
- The fifth unit (U5) was tutored using the Telegram application as well, but in this case using a best effort communication policy.
- Finally, the sixth unit (U6) was managed with a ''periodic responses'' strategy using the Discord platform.

Table 3. Groups configuration. Statistical data

Subject	Total number of students			Mean age			Standard deviation in age			Women percentage		
	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021
DS	12	15	21	18.5	18.3	18.6	0.2	0.3	0.3	50%	47%	48%
CA	11	13	16	20.7	21.8	21	0.4	1.9	1.1	36%	38%	50%
OOD	12	16	23	20.3	22	21.4	0.9	2.3	1.2	42%	31%	52%
CS	73	87	124	21.7	21.4	21.5	0.8	0.5	0.3	39%	41%	36%
GI	7	5	11	25	25.3	25.6	0.3	0.3	0.4	29%	40%	28%

At the end of each unit, students were evaluated. All students in the pilot groups were evaluated in a similar way. Practical exercises had a weight of 50% on the final mark, while final tests had the remaining 50% of the weight. All activities were evaluated through evaluation rubrics, defined at the very beginning of the experience. Official solutions to be manually evaluated by professors must be submitted to the official e-learning platform before the due date. All due dates are fixed after completing all theoretical sessions about each unit. Besides, at the end of each unit, students responded to a very short survey with only six short questions using the Likert scale [24] (strongly agree to strongly disagree) to answer. Surveys were collected online.

4.3 Results and Discussion: Academic Results

All academic results were collected and statistically processed. In order to facilitate the statistical processing and the comparison, academic results were normalized. Table 4 shows the obtained results by all pilot groups in every year under study. The same results are represented in Fig. 2 using bar charts. Table 5 shows the normalized academic results for the control group, as a reference.

As can be seen, when a fully online methodology is employed (DS, CA and OOD), there is an improvement in the academic results, except for units U1 and U3. Students in fully online teaching programs tend to be connected for a long time to the LMS and other available tools. Thus, on the one hand, email does not offer the fast interaction usually requested by online students, which makes it very difficult to communicate efficiently (considering that students cannot contact professors in any other way). On the other hand, the forum managed

Table 4. Normalized academic results (pilot groups)

DS												
Year	U1		U2		U3		U4		U5		U6	
	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std
2019	0.625	0.285	0.865	0.210	0.668	0.256	0.976	0.101	0.810	0.204	0.654	0.251
2020	0.602	0.255	0.786	0.302	0.675	0.235	0.965	0.09	0.823	0.210	0.624	0.280
2021	0.698	0.187	0.856	0.219	0.687	0.244	0.884	0.110	0.801	0.267	0.639	0.264
CA												
Year	U1		U2		U3		U4		U5		U6	
	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std
2019	0.921	0.103	0.705	0.254	0.800	0.302	0.781	0.123	0.631	0.120	0.773	0.233
2020	0.932	0.128	0.699	0.276	0.821	0.287	0.801	0.111	0.663	0.123	0.763	0.223
2021	0.965	0.154	0.701	0.244	0.849	0.290	0.650	0.106	0.612	0.154	0.702	0.242
OOD												
Year	U1		U2		U3		U4		U5		U6	
	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std
2019	0.598	0.301	0.853	0.227	0.687	0.245	0.893	0.102	0.754	0.176	0.994	0.189
2020	0.635	0.234	0.797	0.310	0.664	0.237	0.924	0.08	0.749	0.201	0.980	0.223
2021	0.601	0.267	0.777	0.302	0.659	0.256	0.889	0.110	0.755	0.189	0.932	0.219
CS												
Year	U1		U2		U3		U4		U5		U6	
	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std
2019	0.701	0.265	0.956	0.178	0.689	0.249	0.976	0.08	0.923	0.158	0.890	0.188
2020	0.669	0.277	0.923	0.154	0.720	0.201	0.945	0.115	0.834	0.210	0.888	0.225
2021	0.686	0.288	0.945	0.210	0.710	0.198	0.956	0.107	0.844	0.197	0.891	0.207
GI												
Year	U1		U2		U3		U4		U5		U6	
	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std
2019	0.885	0.256	0.878	0.276	0.936	0.301	0.601	0.301	0.729	0.143	0.755	0.154
2020	0.901	0.198	0.934	0.198	0.922	0.305	0.612	0.312	0.719	0.133	0.779	0.108
2021	0.870	0.248	0.923	0.189	0.963	0.288	0.644	0.256	0.725	0.134	0.733	0.177

Table 5. Normalized academic results (control groups)

Subject	U1		U2		U3		U4		U5		U6	
	Mean	**std**	**Mean**	**std**	**Mean**	**std**	**Mean**	**std**	**Mean**	**std**	**Mean**	**std**
DS	0.606	0.297	0.770	0.380	0.679	0.246	0.814	0.163	0.773	0.255	0.634	0.271
CA	0.959	0.130	0.776	0.351	0.841	0.292	0.551	0.324	0.568	0.263	0.737	0.273
OOD	0.656	0.304	0.638	0.223	0.673	0.392	0.651	0.321	0.529	0.276	0.934	0.279
CS	0.698	0.286	0.871	0.215	0.710	0.254	0.743	0.149	0.754	0.224	0.699	0.350
GI	0.880	0.279	0.849	0.341	0.956	0.317	0.555	0.330	0.696	0.163	0.757	0.196

through a ‘‘response as the last option’’ strategy does not generate a sustainable increase in the academic results. In general, online students need a fluent interaction with professors and, in its absence, they create informal networks with other students. But they use different platforms (such as WhatsApp or Discord) to host them, different from the institutional LMS. On the contrary, for the remaining units and communication tools and strategies there is a sound improvement in the

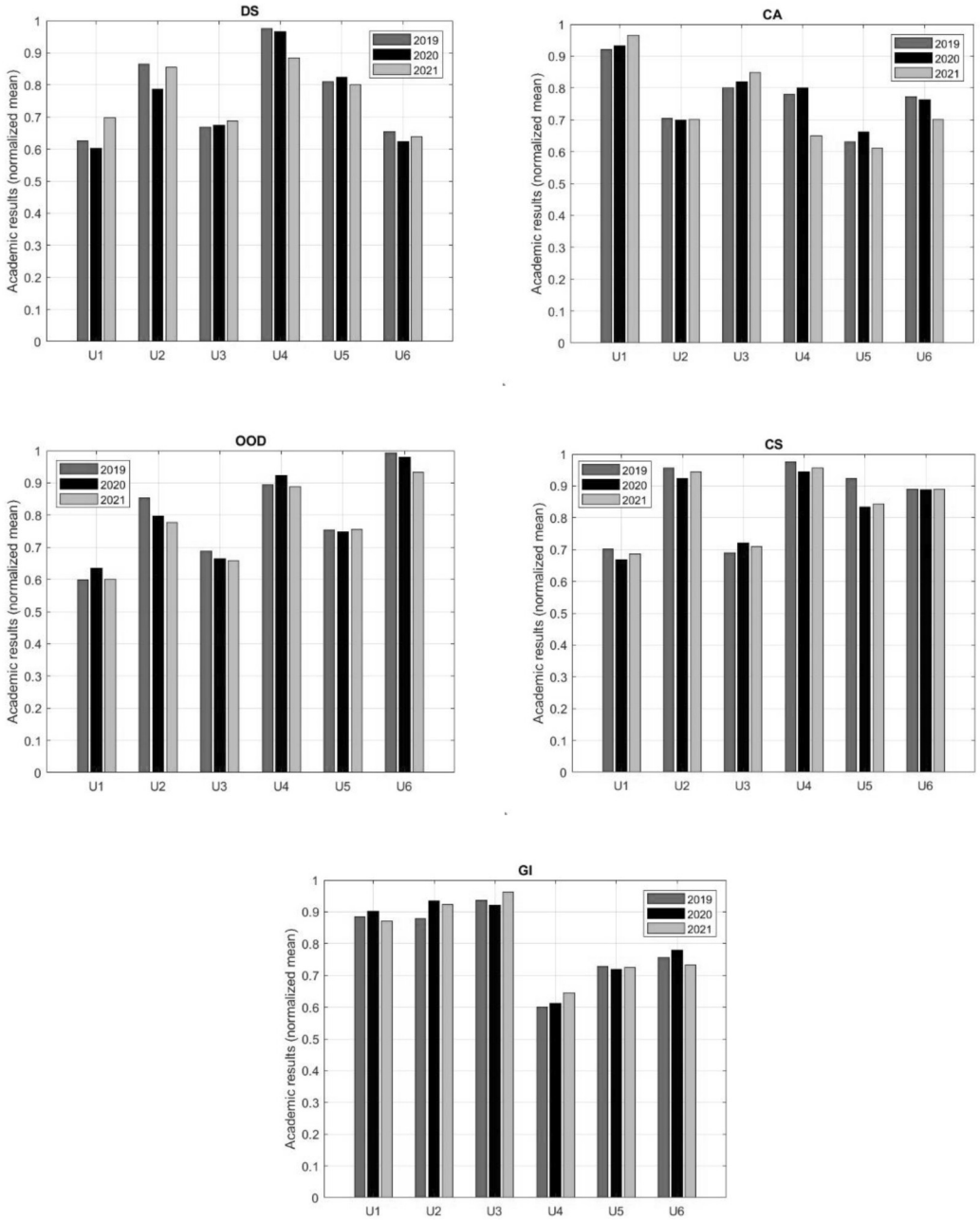

Fig. 2. Normalized academic results (pilot groups).

academic results, between 10% and 20% (depending on the specific situation). A particularly interesting instructional tool is Telegram, as it was very successful in enabling students to improve their marks. This improvement is especially relevant when an ''immediate response'' communication policy is applied, when results increased to 52% (OOD, U4, 2020 and 2021). Furthermore, although Discord also includes a chat function, since the applied communication strategy (''periodic responses'') reduces the professors' presence compared to the ''immediate response'' communication policy applied with Telegram, the improvement in academic results is less relevant.

These results are consistent with other previous works in which it was clearly shown that students prefer the instant nature and timeliness of chatting [39]. Although these studies are usually focused on live chats [40], similar results have been reported for tools such as WhatsApp [41] or even Twitter [42]. However, considering our results, we can surely confirm that students value the ''immediate response'' communication strategy more than the chat tool itself. This observation is, in fact, consistent with other previously reported results [43], where professors with only the role of chat organizers could not achieve the expected impact in their distance learning experiences. Moreover, our results are also consistent with the state of the art in student preference for immediate responses: some authors have reported experiences where automatic chatbots with automatic responses can have an equivalent impact in higher education students than real professors answering questions using a chat application [44].

Regarding subjects based on blended teaching methodologies (CS), observations are partially different. In pilot groups where the ''response as last option'' communication strategy was employed, no relevant improvement in academic results was observed in fully online methodologies. However, any other communication option (tool or strategy) for the tutorial action caused an improvement in the mean mark of the group of students. In particular, improvement is especially relevant (up to 25% for U5 2019) when using a tool with real-time chat functionality (such as Discord or Telegram). Where all kinds of activities in the Dale's cone can be organized and performed. In this case, the improvement does not appear to be influenced by the specific communication policy applied by professors, as ''best effort'', ''immediate response'' and ''periodic responses'' strategies are causing a similar improvement in the mean mark (U4, U5 and U6). Furthermore, the dispersion in academic results also reduces (up to 50%, approximately), so tutorial action not only improves the average results but also tends to homogenize the achievements of the students. On the other hand, tools with no chat functionality, although they also caused an improvement in the average mark and a reduction in the dispersion of academic results, the impact is less relevant. Actually, as the tool is further from a chat application, improvement is less relevant. In that way, academic results are more positive if the tutorial action is supported by forums (U2) than if it is supported by traditional email (U3). For these cases, the improvement is between 5% and 10%. This general improvement for almost any combination of communication tools and strategies may be explained by more intense in-person contact between students and professors in blended methodologies. Students had the opportunity to ask urgent questions directly to professors during in-persona sessions, so tutorial action is more focused on additional explanations, clarifications, etc. which do not require a synchronous or very fluid conversation. Asynchronous methos are as valuable as the synchronous ones.

Finally, for blended methodologies but with fully in-person sessions (GI), improvement appears to be less relevant for all pilot groups, instructional communication tools, and communication strategies. In this case, improvement is the academic results may also be seen, but is pretty similar for all situations. The average mark increased around 3% regardless of the tool or communication policy. The standard deviation was reduced by a similar percentage. Clearly, in-person contact between professors and students increases, the impact of remote tutorial action tools and activities reduces. Students address topics related to the subject during in-person sessions, so the use of the tutorial tool is less important and is only useful for informative messages, curiosities, and other similar iterations that have little impact on the final academic results. In any case, an improvement may be observed as in all previous methodologies.

This limited impact of instructional communication tools and strategies on the academic results of students following blended methodologies is consistent with the current state of knowledge. Previous works have already identified chats, email or text messaging (among other tools) as key elements to enable human-to-human interaction in blended learning methodologies [45]. But they have also discovered the real impact of specific procedures and instruments to cover the academic needs. Furthermore, experts have reported the way blended learners feel and understand communication tools (regardless of the communication policy) in different ways [46]: email is employed for collaborative evaluation, forums are preferred for critical thinking, and chat applications are understood

as a way of customization. These differences may also explain the lower impact of these tools on global academic results.

Although Table 4 and Table 5 show evidence of a relevant improvement in academic results when the appropriate communication tools and strategies are applied, a scientific statistical analysis is needed before extracting any final conclusions. We employ a Mann-Whitney U test to perform those analyses. The Mann-Whitney U test is a nonparametric test of the null hypothesis that two samples come from the same population against an alternative hypothesis, comparing the mean values of the two samples. It is used to evaluate whether two different data populations are similar or different (higher or lower). The p-value indicates the significance level of the Mann-Whitney U test. Table 6 shows the results obtained from this statistical test, as well as Fig. 3.

As can be seen, in the online teaching methodologies (DS, CA and OOD), the most significant improvement in the academic results is obtained in the U4 unit, when Telegram is managed with an ''immediate response'' communication policy. This conclusion is consistent with the results previously analyzed in Tables 4 and 5. In addition, other pilot groups where communication tools or strategies enable a very fluent information flow between

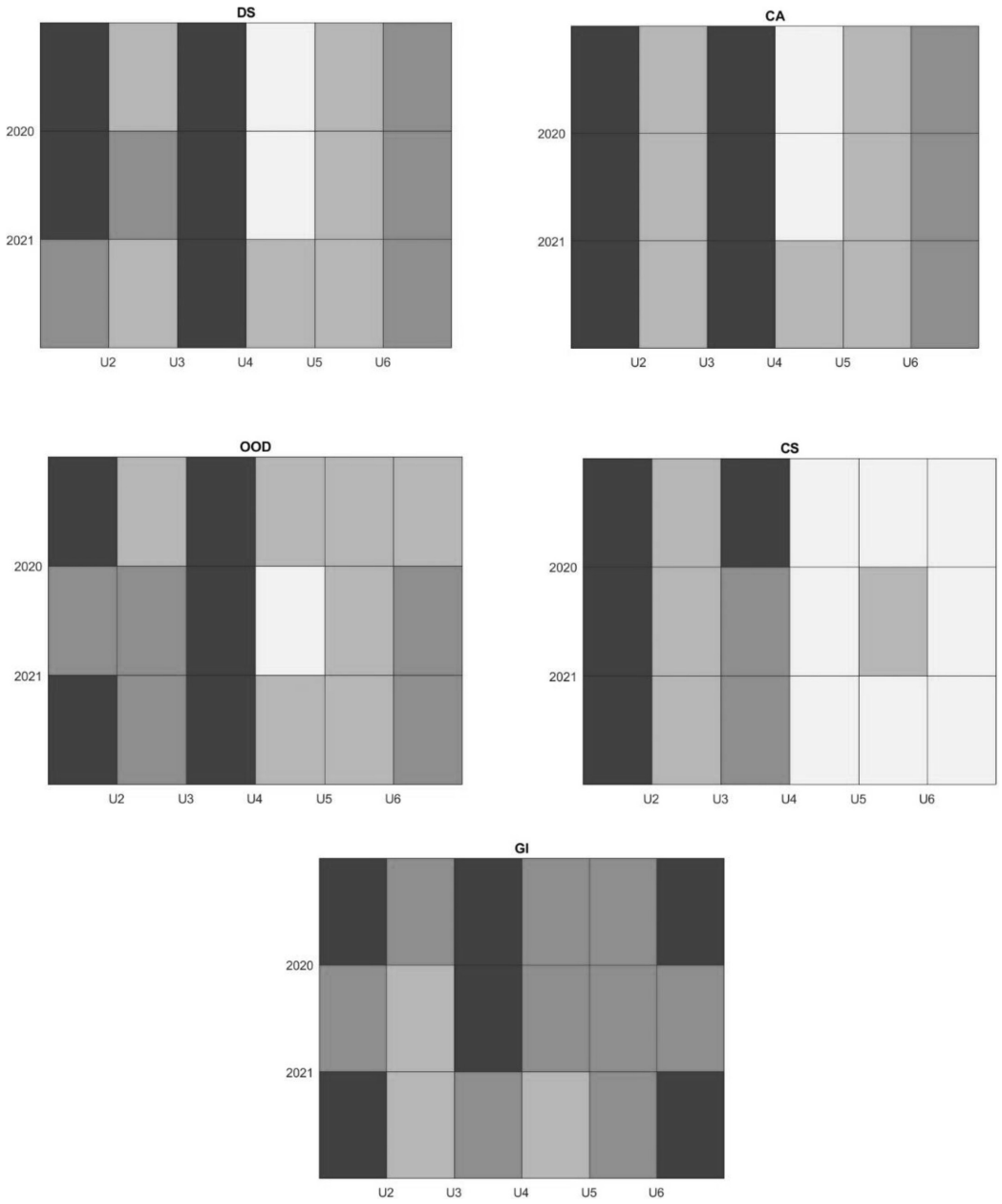

Fig. 3. Academic results (Mann-Whitney U statistical test). Dark: not significant; medium-dark: significant at $p < 0.05$; medium-light: significant at $p < 0.005$; light: significant at $p < 0.001$.

professors and students also show a significant improvement in academic results, although they are more relevant than the one observed in U5. This is the case of "best effort" communication policy or the Discord platform. In fact, Discord and Telegram are the instructional tools where a larger catalogue of activities from the Dale's cone can be organized and performed. Then, in online methodologies (where there are no in-person activities to compensate flaws in the instructional tools), students' learning is significantly improved when selected tools promote collaborative work, a feeling of connection, etc.

For blended teaching methodologies (CS), significant improvements are achieved in more circumstances and pilot groups (for all but not for U1). As said before, this may be caused by a stronger in-person contact between professors and students for urgent issues, so the remote tutorial action is aimed at clarifications, additional information, etc. Activities that cannot be organized with instructional tools, can be then supported by in-person actions. And students' learning is not so dependent on the selected tool. In that circumstance, communication policy is not as relevant as in online methodologies, while students get the expected information at some point. However, significance depends on the selected tool. As analyzed before, improvement is more significant when tools with chatting functionalities are employed (such as Telegram or Discord in U4, U5 and U6), while it decreases as the selected tool is less similar to a chat: forums (U2) and email (U3), following that order.

Finally, in blended methodologies, but with fully in-person sessions (GI) significant improvements in the academic results are observed for all instructional communication tools and strategies, but significance levels are the lowest among all the subjects and methodologies. This, as said before, is clearly caused by a reduced impact of tutorial activities on the final marks, and a lower impact of the specific selected instructional tool in the students' learning. The information and activities conducted through the tutorial action were based on informative articles, newsletter, etc. which has a sparse relation with academic results.

Now, we can answer the first research question, RQ#1. Instructional communication tools and strategies may have an impact on student academic results and enable an improvement. This improvement in online teaching methodologies, is especially relevant when chat applications and immediate responses are provided. In blended methodologies, chat applications are clearly preferred, although improvement may be achieved with almost any tool. Professors may, in this case, choose the most suitable tool for them. Finally, in blended methodologies but with fully in-person sessions, improvement is also achieved, for all tools and communication strategies (although with less significance than in other methodologies). Therefore, we can answer the RQ#1 in a positive way.

4.4 Results and Discussion: Surveys

The academic results allowed us to answer the first research question, but two additional questions are pending. To answer these last two questions a study based on surveys was carried out each year for each unit in every subject. As said in Section 4.2, surveys were based on six simple questions that students could answer online. Responses were based on the Likert scale, ranging from "Strongly agree" (represented by number five) to "Strongly disagree" (represented by the unit). Questions are related to two topics: their motivation (SQ#1, SQ#2 and SQ#4) and how they feel about their new competencies and qualification (SQ#3, SQ#5 and SQ#6). The six questions asked were as follows:

- SQ#1: I felt challenged to go deeper in the proposed units.
- SQ#2: The subject caught my interest.
- SQ#3: I think my competencies are valued by companies.
- SQ#4: In the subject I worked with useful technologies.
- SQ#5: I feel prepared to employ the technical contents I learnt.
- SQ#6: I have acquired the expected competencies.

Table 7 and Fig. 4 show the results of the students' survey, aggregating the responses from all years for the pilot groups and employing the Mann Withey U test to analyze and identify significant differences between pilots and the control groups. As can be seen, there is a great correlation between significant improvements in academic results and significant improvements in student motivation and their level in the competence acquisition. Globally, questions related to the acquisition of competencies show a more general improvement than the motivation of students. But both are significantly better in the pilot groups.

Taking into account the different teaching methodologies, the observations are pretty similar to those made in Section 4.3. In subjects based on a fully online teaching methodology (DS, CA, and OOD), no significant improvement in student motivation or their level of acquisition of competence was observed in U1 and U3 pilot groups. Communication strategies were not fluent enough to allow students to get the information they need and feel on board in the subject. In contrast, strategies such as "immediate response" or tools such as Telegram

Table 6. Academic results (Mann-Whitney U statistical test)

DS												
	U1		**U2**		**U3**		**U4**		**U5**		**U6**	
Year	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**
2019	8.147E-2	NS	3.134E-3	**	2.785E-1	NS	9.649E-4	***	2.572E-3	**	1.419E-2	*
2020	9.058E-2	NS	6.324E-3	*	5.469E-1	NS	1.576E-4	***	4.854E-3	**	4.218E-2	*
2021	1.27E-2	*	0.475E-2	**	9.575E-2	NS	2.706E-3	**	4.003E-3	**	9.157E-3	*
CA												
	U1		**U2**		**U3**		**U4**		**U5**		**U6**	
Year	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**
2019	7.922E-2	NS	0.357E-2	**	6.787E-2	NS	3.922E-4	***	3.060E-3	**	0.462E-1	*
2020	9.595E-2	NS	3.491E-3	**	7.577E-2	NS	6.555E-4	***	0.318E-2	**	0.971E-2	*
2021	6.557E-2	NS	3.340E-3	**	7.431E-2	NS	1.712E-3	**	2.769E-3	**	8.235E-2	*
OOD												
	U1		**U2**		**U3**		**U4**		**U5**		**U6**	
Year	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**
2019	6.948E-2	NS	0.344E-2	**	7.655E-2	NS	5.898E-3	**	3.094E-3	**	4.797E-3	**
2020	3.171E-2	*	4.387E-2	*	7.952E-2	NS	4.456E-3	***	3.547E-3	**	6.551E-3	*
2021	9.502E-2	NS	3.816E-2	*	1.869E-1	NS	6.463E-3	**	2.760E-3	**	1.626E-2	*
CS												
	U1		**U2**		**U3**		**U4**		**U5**		**U6**	
Year	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**
2019	1.190E-1	NS	3.404E-2	**	7.513E-2	NS	6.991E-4	***	5.472E-4	***	2.575E-4	***
2020	6.984E-2	NS	3.853E-2	**	2.551E-2	*	8.909E-4	***	3.386E-3	**	8.407E-4	***
2021	9.597E-2	NS	2.238E-2	**	5.060E-3	*	9.593E-4	***	1.493E-4	***	2.543E-4	***
GI												
	U1		**U2**		**U3**		**U4**		**U5**		**U6**	
Year	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**	**p-value**	**significance**
2019	8.143E-2	NS	3.50E-2	*	6.160E-2	NS	8.308E-3	*	9.172E-3	*	7.537E-2	NS
2020	2.435E-2	*	1.966E-3	**	5.733E-2	NS	5.853E-3	*	2.858E-2	*	3.804E-2	*
2021	9.293E-2	NS	2.511E-3	**	3.517E-2	*	4.497E-3	**	7.572E-3	*	5.678E-2	NS

NS not significant; * significant at $p < 0.05$; ** significant at $p < 0.005$; *** significant at $p < 0.001$.

Table 7. Surveys results (Mann-Whitney U statistical test)

DS												
	U1		U2		U3		U4		U5		U6	
Year	p-value	significance	p-value	significance	p-value	significance	p-value	significance	p-value	significance	p-value	significance
SQ#1	6.685E-2	NS	9.337E-3	*	9.880E-2	NS	8.828E-4	***	4.504E-2	**	6.732E-3	*
SQ#2	2.068E-1	NS	8.11E-3	*	8.641E-2	NS	3.137E-3	**	2.057E-4	***	6.643E-3	*
SQ#3	6.539E-2	NS	4.845E-2	**	3.889E-1	NS	4.583E-3	**	8.997E-3	**	1.228E-2	*
SQ#4	6.721E-2	NS	7.567E-3	**	4.547E-1	NS	4.989E-3	**	7.626E-3	**	4.073E-2	*
SQ#5	4.067E-2	*	4.170E-2	**	2.467E-1	NS	1.489E-4	***	8.825E-3	**	2.753E-3	**
SQ#6	6.669E-3	*	9.718E-3	**	7.844E-2	NS	8.997E-4	***	2.850E-2	**	4.167E-3	**
CA												
	U1		U2		U3		U4		U5		U6	
Year	p-value	significance	p-value	significance	p-value	significance	p-value	significance	p-value	significance	p-value	significance
SQ#1	2.834E-1	NS	4.344E-3	**	8.844E-2	NS	1.170E-4	***	3.466E-3	**	9.509E-3	*
SQ#2	8.962E-2	NS	3.096E-3	**	7.209E-2	NS	8.147E-4	***	5.619E-3	*	7.223E-3	*
SQ#3	3.900E-1	NS	4.747E-3	**	0.186	NS	3.249E-4	***	3.958E-3	**	4.001E-2	*
SQ#4	4.979E-1	NS	3.260E-4	***	6.748E-2	NS	2.462E-4	***	3.981E-2	*	8.319E-3	*
SQ#5	8.266E-2	NS	4.564E-3	**	4.385E-1	NS	3.427E-4	***	4.154E-3	**	1.343E-2	**
SQ#6	6.948E-2	NS	4.138E-3	**	4.378E-1	NS	3.757E-4	***	3.575E-3	**	0.305E-2	**
OOD												
	U1		U2		U3		U4		U5		U6	
Year	p-value	significance	p-value	significance	p-value	significance	p-value	significance	p-value	significance	p-value	significance
SQ#1	0.842E-1	NS	0.454E-2	**	9.969E-2	NS	0.410E-2	**	4.135E-3	**	8.979E-3	*
SQ#2	1.639E-1	NS	1.465E-2	*	5.535E-2	NS	8.877E-4	***	4.186E-3	**	5.934E-3	*
SQ#3	3.242E-1	NS	6.311E-3	*	5.155E-2	NS	0.446E-2	**	4.862E-3	**	5.038E-3	*
SQ#4	3.017E-2	*	4.593E-3	**	3.307E-1	NS	4.362E-4	***	4.311E-3	**	6.128E-3	*
SQ#5	0.117	NS	4.742E-3	**	4.300E-1	NS	8.266E-4	***	1.908E-3	**	8.194E-3	*
SQ#6	5.399E-1	NS	4.708E-3	**	4.918E-1	NS	3.945E-4	***	2.586E-3	**	5.319E-3	*
CS												
	U1		U2		U3		U4		U5		U6	
Year	p-value	significance	p-value	significance	p-value	significance	p-value	significance	p-value	significance	p-value	significance
SQ#1	2.021E-1	NS	4.202E-3	**	6.948E-3	*	3.864E-4	***	7.842E-4	***	0.503E-4	***
SQ#2	4.539E-1	NS	3.469E-3	**	4.265E-2	*	7.756E-4	***	7.056E-4	***	2.287E-4	***
SQ#3	4.279E-1	NS	4.170E-3	**	8.363E-3	*	7.343E-4	***	1.093E-4	***	8.342E-5	***
SQ#4	9.661E-2	NS	5.567E-4	***	7.314E-2	NS	4.303E-4	***	3.899E-5	***	0.156E-4	***
SQ#5	6.201E-3	*	1.565E-3	**	3.600E-2	*	6.938E-4	***	5.909E-5	***	8.637E-5	***
SQ#6	6.954E-3	*	4.621E-3	**	4.542E-2	*	9.452E-4	***	4.594E-5	***	0.781E-4	***
GI												
	U1		U2		U3		U4		U5		U6	
Year	p-value	significance	p-value	significance	p-value	significance	p-value	significance	p-value	significance	p-value	significance
SQ#1	6.690E-2	NS	5.996E-3	*	8.322E-2	NS	1.080E-2	*	8.487E-3	*	5.078E-2	NS
SQ#2	5.002E-3	*	0.560E-2	*	6.174E-3	*	5.170E-3	*	9.168E-3	*	5.856E-3	*
SQ#3	2.180E-2	*	0.363E-2	**	5.201E-3	*	1.432E-3	**	9.870E-3	*	7.629E-3	*
SQ#4	5.716E-3	*	1.525E-2	*	8.639E-2	NS	4.594E-3	**	5.051E-3	*	0.830E-1	NS
SQ#5	1.222E-2	*	0.196E-2	**	0.977E-3	*	0.046E-1	**	2.714E-2	*	6.616E-3	*
SQ#6	6.712E-3	*	4.352E-2	*	9.081E-3	*	4.667E-3	**	1.008E-2	*	5.170E-2	NS

NS not significant; * significant at $p < 0.05$; ** significant at $p < 0.005$; *** significant at $p < 0.001$.

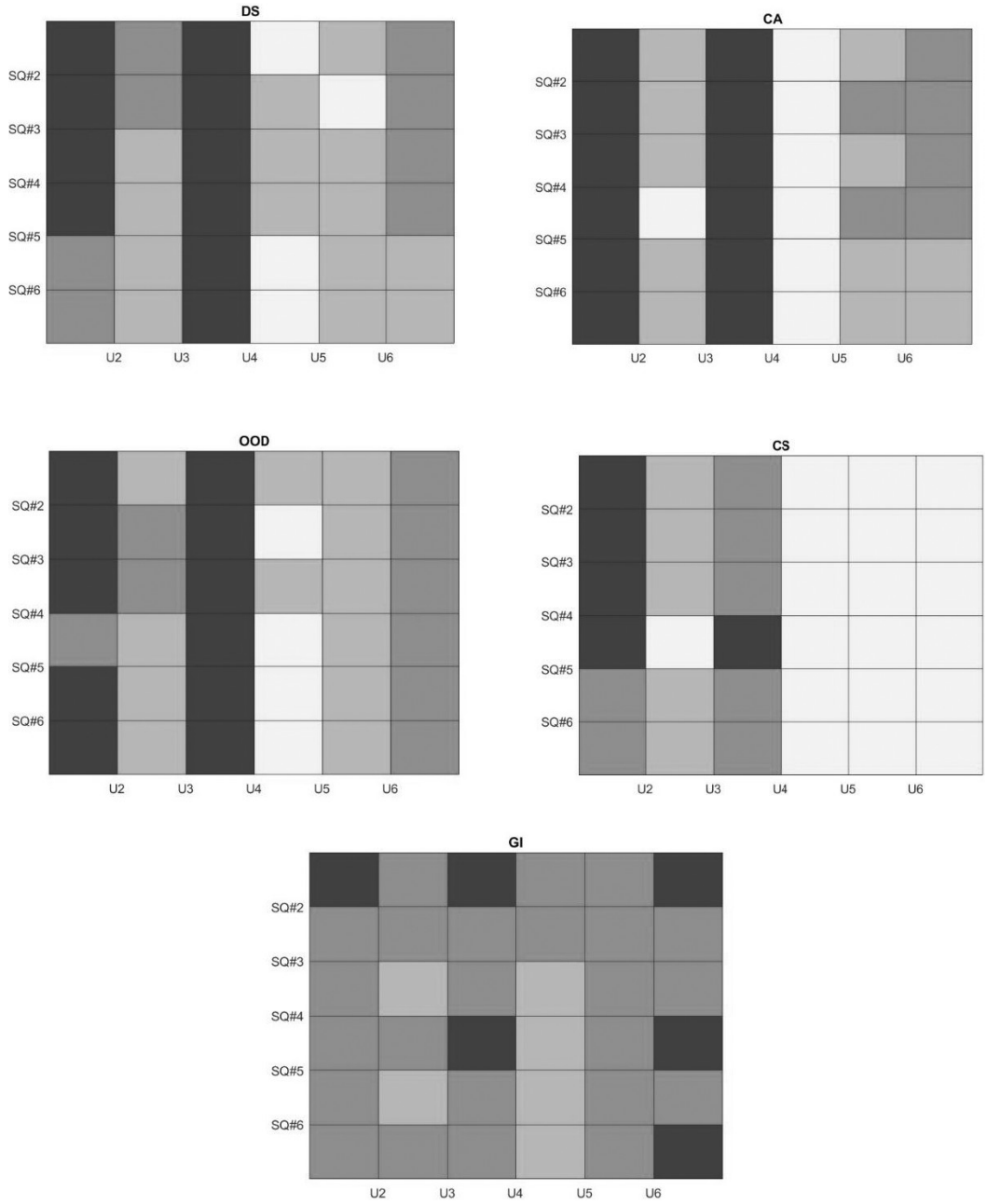

Fig. 4. Academic results (Mann-Whitney U statistical test). Dark: not significant; medium-dark: significant at $p < 0.05$; medium-light: significant at $p < 0.005$; light: significant at $p < 0.001$.

present a very significant improvement in both dimensions. The synchronous components provided by instructional tools such as Telegram prevent students to feel disconnected and enable a higher learning level. But in online methodologies it is essential the selected instructional tool enable all kinds of activities in the Dale's cone. As no in-person actions can be designed or carried out, the students' learning is very sensible to the selected tool.

In blended methodologies (CS), on the other hand, the impact is also significant, but the increase in student motivation and the acquisition of skills is more related to the selected instructional communication tools than to the communication policy. The biggest (positive) impact is associated, as improvement in the academic results, to tool with chatting functionalities (such as Discord or Telegram -U4, U5 and U6-). Using these tools, collaborative learning is promoted, and the global students' learning improved more significantly. The significance level of the achieved improvement reduces as the employed application is more different from a chat application. In that way, forums (U2) generate a slightly less significant impact, while when using the email in the tutorial action, the impact is limited (U3).

Finally, in blended methodologies, but with fully in-person sessions, a significant improvement is also observed in the motivation and the level of competence acquisition. In this case, this improvement is transversal to all communication tools and strategies (or policies) but is less significant than the one achieved in other previously discussed methodologies. As said in Section 4.3, the main reason for this behavior is the physical availability of professors during in-person sessions. In-person activities may mitigate the flaws and deficiencies in instructional tools. Then, the weight of tutorial activities and communications in student learning is less relevant.

This clear difference between online and blended methodologies is also consistent with existing knowledge. Previous authors have reported how online students tend to feel the teaching team cared more about them and were more satisfied than students in blended methodologies [39] (when using exactly the same tools and implementing equivalent tutorial actions).

In conclusion, the communication tools and strategies have a (positive) impact in the online and blended learning methodologies.

Taking into account all these observations and the results of the Mann Withey U test, we can answer the remaining two research questions (RQ#2 and RQ#3) in a positive way: instructional communication tools and strategies have a positive impact on student motivation and acquisition of skills. Specifically, in fully online subjects, the highest improvement is reached for fluent and very agile communication strategies. However, in blended methodologies the most significant impact is associated with chatting applications. While in blended methodologies but with fully in-person sessions the impact is general, regardless of the employed tool or communication strategy, but less significant.

4.5 Validity Threats and Limitations

Although all scientific standards and good practices were followed, the proposed experiments have some limitations and there are some threats to the validity of the results.

When analyzing the impact of instructional communication tools and strategies in blended and online methodologies, the proposed experiences focus on the students' vision. Although currently the Higher Education European Area follows a student-centered approach and quality assurance is based on students' opinions, this approach does not control other possible parameters such as the level of competencies in Bloom's taxonomy that are acquired, the professors' workload, or the employers' opinion about alumni learning.

Regarding internal validity, there may be a possibility that students' answers about their motivation and learning are not fully accurate. Furthermore, since the experience was conducted over several years, some students could be aware of the experiment because of information provided by previous students. That may also affect the results. Moreover, a potential major threat is related to the evaluation criteria. Although evaluation rubrics were defined in the very first year and were used throughout the experience, some variations, and exogenous effects (such as comparing students from different courses) may appear.

On the other hand, and with regard to the external validity, all the participants in our experience had a technological background and were enrolled in technological courses. Results could not be generalized to other profiles.

Finally, in this paper, we are using a nonparametric statistical test (Mann–Whitney U test). Some authors claim that parametric tests are more powerful than the nonparametric test, but very little power is lost in the Mann–Whitney U test, which is one of the most powerful nonparametric tests [28].

5. Conclusions and Future Work

This paper evaluates the impact of communication instructional tools and strategies in blended and online teaching methodologies. The study considers five subjects analyzed during three different courses. Four different communication instructional tools were also studied, including forums, emails, Telegram, and Discord. Furthermore, four different communication strategies were also considered. Three research questions are introduced. To answer those questions, two different sources of information are used: the students' academic results and the responses of the surveys. All three research questions were answered in a positive way. Fully online teaching methodologies and blended methodologies are highly enriched when chat applications are employed in the tutorial action. The online subjects improve the most when communication strategies such as 'immediate responses' are implemented. On the other hand, in blended methodologies but with fully in-person sessions, the impact is less relevant, although still a significant improvement is achieved in academic results, students' motivation and level of competence acquisition.

In practical scenarios, and considering the obtained results, we highly recommend the implementation of chat tools (Telegram) in courses where blended or online methodologies are employed. These tools, on the other hand, present some management problems: students must be added manually, there is not automatic update with every new semester or year, they have no easy connection to institutional Learning Management

Systems (LMS), etc. Then we recommend those tools only for small or medium-sized groups (no more than thirty people). For larger groups, other tools such as Moodle forums would be more efficient, although the a priori impact could be lower. In addition, immediate response policies are recommended to be implemented, but only for professors with a limited workload (no more than two subjects per term). This communication strategy has a great impact, but it is complicated to manage in a large catalogue of subjects at the same time. For educational professionals with a higher workload, we recommend considering other approaches such as ''periodic interactions'', which can be easily scheduled.

Future works will analyze the impact of the instructional communication tools and strategies proposed in other educational contexts that are not technological. For example, future work will analyze the performance of those tools and strategies in programs with highly practical scientific or social abilities, such as linguistics or medicine. On the other hand, future works will also implement the most successful approaches for each learning methodology in all subjects, looking for the best configuration of specific tools (and communication strategy) configuration and secondary effects (such as fatigue in students caused by a very intense tutorial action).

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