HOW INDIVIDUAL LEARNING MODELS AND DIDACTIC METHODOLOGIES WILL CHANGE AFTER THE CORONAVIRUS PANDEMIC: THE CASE OF CONCURRENT ENGINEERING

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ABSTRACT

Numerous scientific research studies have addressed the impact of social interaction processes on the mechanisms that regulate the levels of individual learning and on teaching methods.
The role of social interactions is particularly evident in concurrent and collaborative environments, such as the Concurrent Design Facility (CDF), developed and successfully operating at ESTEC since 1998.
Concurrency and collaborative approaches are as much cultural as social mind-sets and a key factor in the success of concurrent engineering practices lies in establishing the right alchemy between technical challenges and social interactions.
The paper analyzes the effects on people's processes and learning levels as a result of the transformations caused by the digital revolution and the global pandemic, highlighting some potentially positive evolutions.

1. INTRODUCTION

Numerous scientific research studies have addressed the impact of social interaction processes on the mechanisms that regulate the levels of individual learning and on teaching methods.
According to these theories, individual learning, considering the human being, in a systems theory perspective, as a living system dynamically interacting with its environment, does not depend only on individual factors [such as "motivation to learn" (Mo), "emotional convolution" (Em) and "memorization processes" (Me)], but also on the effects of "social interaction" (Is).
The level of individual learning (Ai) depends on the multiplicative combination of individual factors and social interactions:

$$\mathbf{Ai = (Mo, Em, Me) * Is}$$

As shown by A. Bandura [1] in his studies on individual learning processes and on the impacts from mutual observation between individuals, learning depends on those contents of knowledge and technical skills ("know-how") that people acquire by observing others. In other words, learning is based, "inter alia", on strong competing social interactions.
The role of social interactions is particularly evident in concurrent and collaborative environments, such as the Concurrent Design Facility (CDF), developed and successfully operating at ESTEC (Fig.1).

Figure 1: ESTEC Concurrent Design Facility

Concurrency and collaborative approaches are as much cultural as social mind-sets and a key factor in the success of concurrent engineering practices lies in establishing the right alchemy between technical challenges and social interactions.
Nowadays we are faced with the need to reformulate our theories and best practices as a result of two paradigmatic and disruptive changes: the digital revolution on one side and the global social-economic effects of the Coronavirus pandemic on the other. Both move in the same direction of change, amplifying its effects: virtualization/remotization of learning and working interactions and social distancing.
From a broad perspective, the pandemic, with all its tragic effects, is just accelerating an already existing societal transformational process: the progressive dematerialization and virtualization of many productive activities, mainly in the service sector.
The challenge we are now facing is that of extending this paradigm to activities highly dependent on intellectual interactions and knowledge-intensive: engineering, medicine, and education.

2. BASIC CONCEPTS AND DEFINITIONS

It might be useful to better define the meaning of three terms often used in this paper and to provide some definitions.
Concurrent engineering, as already stated, is a technical approach and mindset even before being a methodology. Concurrency means looking at the engineering of a product, system, or service with a truly systemic and holistic view, considering all aspects of the life-cycle: design, development, production, operations, logistics, and evolution (or retirement/disposal).
From a methodological standpoint, Concurrent Engineering (CE) emphasizes the parallelization of tasks (i.e. performing tasks "concurrently") in the development of a new product and hence it is also sometimes called simultaneous engineering.
With its through-life perspective, Concurrent Engineering represents a drastically new paradigm shift as compared to the "traditional" engineering approach (also known as "waterfall" or "over-the-wall" approach), where tasks were performed sequentially and teams worked separately, in isolated "silos" (Fig.2).

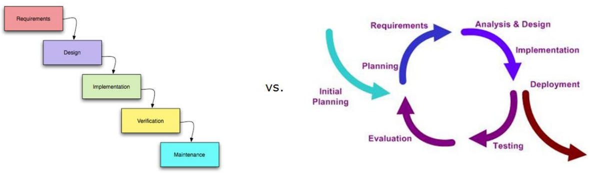

Figure 2: "Waterfall" vs. "Concurrent" engineering process

Collaboration among people is key to the success of a concurrent engineering process.
CE is intrinsically based on multidisciplinary teams, sharing a common teamwork culture, realizing good communication in a collaborative, co-operative environment and, we could even say, sharing the same empathy towards a common vision.
The role of collaboration in all contemporary industrial processes is becoming so important that a specific science, Collaborative Engineering, was developed as a practical application of collaboration sciences to the engineering domain.
Collaborative Engineering is defined by the International Journal of Collaborative Engineering as a discipline that "studies the interactive process of engineering collaboration, whereby multiple interested stakeholders resolve conflicts, bargain for individual or collective advantages, agree upon courses of action, and/or attempt to craft joint outcomes which serve their mutual interests.".
It should be evident that Concurrent Engineering and Collaborative Engineering are not overlapping concepts and approaches, but that they support each other and are closely related.
The practical convergence of the "concurrent" view, more focussed on industrial processes, and the "collaborative" one, more focussed on people and human interactions, is in a Concurrent Design Facility (CDF).

The concurrent engineering approach is based on five key elements:
- a process
- a multidisciplinary team
- an integrated design model
- a facility (CDF)
- a software infrastructure

It is in the physical facility, the CDF, that the non-obvious blend between technical and human factors has to successfully be realized.
This is quite evident in the definition of Concurrent Engineering that we have adopted for the Concurrent Design Facility is: "Concurrent Engineering (CE) is a systematic approach to integrated product development that emphasizes the response to customer expectations. It embodies team values of co-operation, trust, and sharing in such a manner that decision making is by consensus, involving all perspectives in parallel, from the beginning of the product life-cycle."

3. COGNITIVE DYNAMICS, HUMAN INTERACTIONS AND ORGANIZATIONAL BEHAVIOUR IN PRESENTIAL VS DIGITAL COLLABORATIVE ENVIRONMENTS

The digitization of workplaces involves some notable changes that we could even define paradigmatic. One of these is undoubtedly represented by the transformation of the physical workplace, based on the "atomic" dimension of reality, into a digital workspace where "places" are dematerialized and made up of "bits and bytes" [2]. Paradoxically, this profound difference between the two "worlds", the physical and the digital one, makes possible practicing "social distancing" and "interpersonal digital approach" at the same time. That is, someone can be in different physical places at the same time, but in the same digital space.
In this context, one of the elements that have aroused the most considerable interest from researchers is the effect of this radical change on organizational behaviors and in particular on cooperative ones.
Organizational behavior consists of how a person behaves within a particular organizational context [3], such as in a concurrent engineering facility. Organizational contexts influence individual behaviors and the final result may also be profoundly different from the natural propensity of the individual. For example, people with an aggressive and competitive attitude will necessarily have to "behave" in a different way to survive in a social and collaborative context.
Research in psychology has agreed, more or less uniformly, that among all possible models of behavior, even regardless of the animal species in question, the "cooperative/collaborative" one undoubtedly represents the behavioral modality that gives the highest chances of survival. Even in moments of necessary competition, collaboration, and cooperation, albeit temporary, can represent a valid strategy of success (competing cooperation or "coopetition", [4]).
Studies also show that cooperative/collaborative

interactions between subjects, compared to the activities carried out in a competitive and individualistic context, promote the achievement of superior results and have shown that cooperation has positive effects even when in the workgroup there are simultaneously operating subjects with different professionalism and experiences. It is, therefore, reasonable to note that during the performance of group activities, some critical soft skills relating to problem-solving and logical analyses increase in a recordable way, for the benefit of all team members. So individual performances are attested on the levels of individuals with superior skills [5].

It is now a question of verifying what happens when the physical place of cooperation and interaction is missing, and a digital space replaces it.

First of all, we must state that the only area in which research in this sense has been conducted, and where it is possible to make a structured analysis of the literature, is the "education" sector and in particular that of e-learning. The effects on the individual behavior of the adoption of digital solutions in learning processes have been experienced for a long time.

The organizational and methodological changes required in the passage from "concurrent engineering working place" to "concurrent engineering working space", as mentioned, is paradigmatic. For this reason, we need to experiment with innovative organizational methods or otherwise see the numerous advantages of team-working vanish.

If we did not adopt any organizational measures, the individualistic dimension of the team members, now virtual, would tend to take over with all its charge of negativity which would reflect negatively on the overall performance levels.

In the digital working/educational group, it is necessary to keep under control with a great emphasis on all communication processes, that physical distance modifies in depth.

In real places, communication, which is the basis of the cooperation and collaboration process, is enriched by all the non-verbal (e.g. body language) forms of expression and sometimes we understand each other by merely crossing the gazes or observing a particular expression on the face of one's interlocutors.

In online processes, all this vanishes, and we have to integrate the natural communication processes with some surrogate technologies and methodologies.

In our research and professional experience in the e-learning world, we have adopted some solutions which, albeit by modifying the work processes, can help to reestablish the right communication flows in a work context.

First of all, it is advantageous to include a new professional figure in the various organizational processes, which we have defined as a "process tutor", to whom we can entrust the specific role of encouraging the development of adequate communication flows between operators. The process tutor works, obviously online, in a proactive way. This role will be entrusted to young people with professional competence in the domain under discussion, graduates with a couple of years of experience, extroverts, with adequate communication skills and with specific skills in the use of social communication tools. The tutor also verifies the state of functionality of the teleconferencing system, intervenes in the work process, or the educational process if it is an online training activity, encouraging participation and stimulating communication flows between operators.

The tutor also has the task of monitoring the chat discussion between operators. He moderates ongoing discussions and directly intervenes when he can do so. Alternatively, he may, if so deemed necessary, re-focus the work requesting specific attention on topics emerging from the interactions of the team members.

Technologies today also allow to record meetings, place subtitles and index their contents, so that they can be reviewed (which is typical of e-learning), but also reworked to identify, ex-post, any weaknesses or planning errors in the organizational processes, to identify best practices to refer to in the future.

The frequent use of the proactive tutor and the tools outlined can allow the recovery of the dimension of collaboration and cooperation between individuals, albeit in a different form. In this way, following the theory of interpersonal motivational states [6], it is possible to establish a new form of collaborative behavior, called phylogenetic theory. Therefore, behavioral styles change based on new experiences and can generate stable (ontogenetic) changes in individual behavior that will constitute, in the future, the new standard.

In conclusion, we believe that if, on the one hand, the digitization of organizational processes involves radical changes in individual behaviors, worsening the level of interaction between people, on the other hand, technological evolution and people's ability to adapt might compensate this worsening of the organizational conditions [7]. Indeed, new work situations might emerge in which, in different organizational and operational forms, it is still possible to benefit from the advantages deriving from the cooperation between individuals.

What seems important to underline is that we must not try, in a simplistic way, to translate physical environments into digital ones, but rather to exploit all available new technologies and count on the limitless evolutionary adaptation capabilities of mankind.

4. LESSONS LEARNED AT ESA CDF DURING THE COVID 19 PANDEMIC

In the last months, because of the Covid-19 pandemic, the ESTEC CDF had to hold its activities and design sessions in a virtual set-up, with participants remotely connected in audio teleconference (video was not adequate to ensure a good connection quality, given the available internet connection bandwidth and the number of engineers involved.

The experience was challenging, but at the same time very instructive. It confirmed that drawbacks from working remotely were somehow acceptable at the purely engineering level, much more serious and penalizing in terms of the creation of a common team-spirit and interpersonal communications.

Problems were evident in the first phase of a Study (team creation), mainly due to the difficulty in building a common team spirit. In general, the process was less concurrent, lacking, for instance, the spontaneous, relaxed side discussions occurring between team members (e.g. during coffee breaks or at the canteen).

Experts motivation and engagement were as much as possible compensated by planning ad-hoc splinter meetings (as a surrogate to spontaneous chats) where the CDF Systems Team would approach specialists in smaller groups, discussing technical issues but also establishing a human connection that in the CDF would happen exchanging a glance at the right moment. The essential role of the team leader was confirmed and his contribution as a facilitator was further appreciated, both from a technical and a human perspective

The invaluable soft skills of the leader had to be re-invented, with a redefinition of the senses to be used: it was no longer possible to look at the faces of the team members, attempting at decoding doubts, frustration or excitement, but words, pace, tone of the voice became the most important tool for the leader guiding the team.

And all this happened without a preparation but with a strong motivation and resilience, and with the willingness to challenge a situation that nobody would have ever expected.

The team of Systems Engineers involved in CDF Studies and other concurrent activities during the pandemic made time to reflect upon the experience, deriving the following main lessons learned:

1. Remote Concurrent Design Sessions were feasible at an efficiency that is comparable to the standard "in-persona" ones, however this required a significant extra effort from the team. In particular, the Team Leader and Systems Engineers – in their role of Study coordinators – faced a significant overload, having to define new processes and ensuring smooth execution of the sessions with a thorough preparation. Some positive side effects were also experienced, e.g. more efficiency in getting written reports from experts.
2. The Systems Engineering team has identified elements that would have been useful to facilitate the remote experience and increased efficiency. In particular:
   A good digital connection platform, compliant to the IT security policies (e.g. firewalls),
   a. allowing high quality audio and video capability,
   b. envisaging the possibility to share multiple presentations (as a substitute to the CDF multiscreen setup) and draw on the same canvas (as a substitute to the CDF SmartBoard),
   c. including side chats to establish 1-to-connections between specialists when needed
   d. enhancing breakout rooms for virtual splinter meetings
   e. displaying agendas, record of decisions, highlighting actions, etc.

   to make the design experience as real as possible, and relieving the Team Leaders and Systems Engineers from the logistics tasks, so to focus on the design;
3. Higher allocation of resources to the session coordinators – or ad-hoc facilitators - ensuring support to the virtual team, helping the team members in the resolution of all problems (mainly, but not only, technical and logistics) that could impair a smooth proceeding of the discussions;
4. A well-detailed set of working environment guidelines and process procedures for members of virtual teams (which the ESTEC CDF Team started working on already at the first study conducted remotely, for the benefit of the following one).

In conclusion, the "virtual" CDF experience was not negative. Activities were not impaired by the confinement, although requiring more effort in terms of worked hours; new ways of working were defined "on the field"; in some areas, an efficiency increase was noticed (report writing from specialists that could take advantage from flexible working hours).

The main challenge remains, as expected, that of re-establishing in a virtual team the human "empathy" (e.g. deriving from our body language) that is often a source of "storming" in the team creation phase, but also essential in achieving a shared focus to accomplish common goals.

"Human beings are an ultra-social species (…) and our nervous systems expect to have others around us" [8] to work better.

Coping with social distancing is a challenging task and even if the Covid-19 experience has shown and is showing that human beings can adapt to extremely difficult conditions, this induces stress which cannot be sustained for a long period without consequences.

Technology should support as far as possible every-day life activities conceived for a "non-confined world" alleviating from unnecessary stress, and it will surely evolve towards new applications when the pandemic will be resolved. Difficult to make predictions, but hard to expect that all will just go back as it was.

5. TOWARDS VIRTUAL COLLABORATIVE ENVIRONMENTS IN ENGINEERING DESIGN, EDUCATION, AND TRAINING

So far, the paper analyzed the effects on people's processes and learning levels as a result of the transformations caused by the digital revolution and the global pandemic, highlighting some potentially positive evolutions.

In this respect, the pandemic, with all its tragic effects, was just accelerating an already existing societal

transformational process: the progressive dematerialization and virtualization of many productive activities, mainly in the service sector.
The challenge we are now facing is that of extending this paradigm to activities highly dependent on intellectual interactions and knowledge-intensive: engineering, medicine, and education.
Incidentally, in the space sector, the idea of "virtual" academies is not new [9] [10].
Space industries, space agencies, and other space-related institutions feel a strong need to increase their performance through a better qualification of their personnel. This need drives towards a growing effort in training and education programs, with a continuous learning approach. Furthermore, the space sector, which has traditionally been organized along technology and programmatic lines, is facing challenges that require integrated approaches, involving specific business and systems engineering mindsets. To meet these demands, several post-graduate educational programs on space-related subjects were started, particularly in Europe. Existing programs differ, however, substantially in scope and characteristics, coverage and focus, quality, and organization. More importantly, these activities are not coordinated.
With these motivations in mind, some years ago a Virtual Space Academy was proposed, to coordinate space education for post-graduate students and professionals and realize cross-fertilization between the programs to enhance and stimulate space education. The vision was based on a large use of all the available tools for e-learning, such as teleconferencing, webinars, video-recorded lectures.
During the pandemic, traditional universities have managed in a short time to replace the traditional classroom teaching with a virtual one, betting on the possibility to find a valid alternative, through e-learning, to those educational activities, for which the physical presence was considered so far a "sine qua non" requirement.
The effectiveness of these educational/training approaches (as well as that of remote engineering) will depend on how they will be able to take into account the importance of social interactions. One possible way to enhance the emphatic involvement of individuals could be the adoption of innovative technologies, such as augmented and virtual reality. Along with technologies, however, innovative approaches (e.g. at organizational and methodological levels) will have to be conceived and explored.

6. CONCLUSION

Numerous scientific research studies have addressed the impact of social interaction processes on the mechanisms that regulate the levels of individual learning and on teaching methods.
The role of social interactions is particularly evident in concurrent and collaborative environments, such as the Concurrent Design Facility (CDF), developed and successfully operating at ESTEC since 1998.
The paper analyzed the effects on people's processes and learning levels as a result of the transformations caused by the digital revolution and the global pandemic.
A number of precious and rather positive lessons learned were collected. Many challenging issues, however, still remain to be solved.
In conclusion, if on the one hand the digitization of organizational processes, in concurrent engineering and in engineering activities at large, involves radical changes in individual behaviors, worsening the level of interaction between people, on the other hand, technological evolution and people's ability to adapt might compensate for these drawbacks and open new promising perspectives.

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