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Post-lockdown Education: an Overview of a Computer Architecture Discipline

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***Abstract*—During two years of COVID-19 lockdown for Brazilian universities, new online teaching techniques showed us that the main problem with education is learning. If we compare the methods from one hundred years ago and now, we changed technologies, but we kept the same method to learn because we are humans, i.e., we need to socialize. It is necessary to understand reactions, live, and learn together in the same space, real or not. A disruptive approach to learning will likely be based on something other than a metaverse, but on a download to the brain, and it does not exist yet. However, how is this discussion related to computer architecture? Although we understand the concern about education methods and how wide it is, computer architecture is one of the bases of computer science and engineering. New methods that remove socialization in this new post-lockdown educational environment can also partially remove the bases for a good computer scientist or engineer. Despite that, we can try a hybrid approach, and this report paper intents to present a post-lockdown experience about teaching and learning in a computer architecture class.**

***Index Terms*—computer architecture, education, teaching, learning, COVID-19, lockdown**

I. Introduction

The year 2020 started with many doubts due to the COVID-19 pandemic [1], [2], which changed our lives abruptly and until now (2022), we have some consequences. We can find positive issues, but all negative impacts in education [3] need to be seen as negative and not as false positive, which means positive for *inattentive* people. COVID-19 has accelerated some decisions, and for many people, it was an opportunity regardless of all the problems we know about it. In Brazil, the educational practices were remote/online for almost two years. For instance, universities returned to face-to-face (i.e., on-campus or in-person) activities in February/March of 2022. It is relatively easy to understand since vaccination at high rates is very important to reduce the number of severe cases. Consequently, all efforts were directed toward teaching based on new online techniques. This paper focuses on how online experience can influence in-person education in this new post-lockdown education.

Post-lockdown means that we are working without most restrictions since COVID-19 is still present in our lives, and we need to pay attention to some requirements to live and work together. Consequently, we are changing from online to in-person or hybrid activities, although many jobs will be remote from now. In this new era of flexible work, we have new rules related to undergraduate programs in Brazil. Any curriculum can achieve up to 40% of online disciplines [4]. It is optional and should be related to particular demands, such as student profiles, regions, etc. However, we know this new flexibility can also be seen, as an optimistic view, as another opportunity to improve education, in other words, teaching (initially). In general, we can summarize all the advances during this pandemic in teaching methods. It is a shame because we need to see the other side correctly since students need to learn, and learning is the real challenge in education. It is important to highlight that this paper focuses on undergraduate programs with in-person activities [5]. We understand that distance learning [6] can contribute a lot to this discussion. However, the student profile usually differs between face-to-face and online demands. Thus, a curriculum that adds online techniques to a face-to-face approach, i.e., a hybrid curriculum, has a challenge focused on student profiles.

Computers are present in our personal and professional activities and boost innovation and research, regardless of the area. Computer Science (CS) is a priority in some countries, and it should not be different in Brazil. Despite the importance of all computer science fields, it is relatively easy to say that some disciplines, such as Programming (Algorithms), Computer Architecture, Operating Systems, and Compilers compose the kernel of a well-established curriculum. In other words, a Computer Scientist must properly know these fundamental disciplines. In this paper, Computer Architecture is our main scope, so our focus is on it. Although the motivation of this paper is based on the new era of online approaches for in-person education, the problem statement for a computer architecture discipline can be described as follows: scenarios based on hybrid (online + in-person) education can interrupt the connection/synergy between teaching and learning, partially or totally, since this synergy is based on socialization (i.e., reactions and feeling) which is easily found in face-to-face learning. Besides, Computer Architecture is not a priority for some undergraduate students from Computer Science or Computer Engineering that prefer software design with high-level abstractions. Thus, how to improve the synergy for these scenarios in a computer architecture class?

This report paper aims to present a post-lockdown experi-

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ence about teaching and learning in a computer architecture class, discussing a hybrid education approach for the following years. As previously discussed, the pandemic situation accelerated some decisions, and stakeholders need to be prepared for a new educational environment, not about new teaching methods, but learning methods. Students will be on-campus or online, and how to create proper feedback is the synergy we need to reach. The main contribution of this paper is a discussion about educational approaches, scenarios, and future demands based on a computer architecture discipline.

This paper is divided into the following sections: Section II presents related research works about different approaches during the COVID-19 pandemic. Section III shows the content and objectives of a Computer Architecture discipline as background. Section IV describes our experience based on three different scenarios (on-campus, online, and hybrid). Section V presents an overall discussion about current and future challenges related to computer architecture education, and finally, Section VI shows the conclusions of this paper.

II. Related Work

This section presents an overview of online education during the COVID-19 lockdown. According to Beslin [7], from the United Kingdom, there are many lessons to learn. Of course, we have to face problems that impact our lives, but in general, there is a new world that is more accelerated at different educational levels. Communication technologies are widely spread, and many work positions are hybrid (on-site and remote), i.e., flexible, and educational methods follow this trend, at least partially.

There were many concerns about how to explore online/remote classes during the COVID-19 lockdown and, mainly, what were the benefits of that. Jindal et al. [8] presented a study that discusses limitations and improvements in online classes from universities in India. They highlighted the absence of a classroom-like feeling, which can be obvious, but it is essential to understand because new technologies can help us to find this lost feeling. For this reason, and focusing on quality education, the authors proposed a new platform to create a class-like atmosphere for online learning.

Researchers [9] from the University of Vigo, Spain, presented the effort made by the university and a discussion about how teaching during the COVID-19 pandemic can change future education. They used an open-source platform called Big Blue Button [10] to provide an online space for education. In addition, a Moodle platform [11] was used for online tests. Computer Architecture is one of the disciplines addressed by this work. This discipline is divided equally into theory and practice, and the aforementioned online platform was used for an inverted classroom based on recorded lectures. The authors kept the same tool for laboratory experiments called qtARMSim [12], which students needed to install on their computers. As expected, personal contact was not possible, reducing some learning achievements.

The Universitat Politècnica de València (UPV), Spain, adopted two different approaches [13] according to the three waves of COVID-19. For the two first waves, a mix of on-campus and online lectures, and for the third wave, 100% of online lectures. The main problem for both approaches was related to teaching and student assessment. Some cases pointed out three reasons: i) students were not paying attention during online classes, ii) students lost concentration and got confidence since there were recorded videos, and iii) there was no time to watch all videos. The researchers believe that a face-to-face approach can achieve better results based on the motivation of teachers and students.

A research [14] from Universitat Politècnica de Catalunya-BarcelonaTech, Spain, focused on undergraduate student opinions about remote teaching during the COVID-19 pandemic. This work has an interesting conclusion: students prefer in-person classes since remote teaching lacks human contact. Teachers and students agree that online approaches reduce socialization, which is an important factor in learning.

Researchers from the University of Pittsburgh, USA, elaborated a work-in-progress paper about courses during the COVID-19 pandemic [15]. The results showed that students ($\sim$66%) prefer in-person classes being recorded. Although they received lab kits, this study revealed that most students ($\sim$82%) also prefer in-person labs. According to a full paper from the same group [16], synchronous online recorded lectures with labs based on traditional in-person activities are recommended.

Generally, when we read a paper that describes experiences during the COVID-19 pandemic, including periods of lockdown, the conclusion is relatively the same: in-person approaches have the most important variable for learning, i.e., socialization. In other words, this socialization is the synergy between teaching and learning, or teachers and students. This synergy can be lost if we have only an online approach. Due to this reason, in a post-lockdown education, we need to pay attention to methods that keep this synergy. This discussion is relevant since hybrid approaches must explore the best of each world, face-to-face and online. This paper brings this discussion to a Computer Architecture discipline at PUC Minas, which was 100% online during the lockdown. Post-lockdown will have two approaches based on new curricula: Undergraduate Program in Computer Science will be 100% face-to-face, and Undergraduate Program in Computer Engineering will be 50% face-to-face and 50% online, i.e., a hybrid approach.

III. Computer Architecture at PUC Minas

The Computer Science (CS) and Computer Engineering (CE) curricula divide the Computer Architecture (CA) content into three disciplines called CA-I, CA-II, and CA-III, as follows:

- CA-I: computer generations, Boolean logic, logical ports, expressions, simplification, true table, and Karnaugh map. Combinational and sequential logic designs. Overview of computer architectures and memory hierarchy. Digital building blocks. Data representation, numerical bases,

conversion between bases, and prefixes. Hardware description language.
- CA-II: instruction set architecture, performance analysis, and evaluation, single-cycle datapath, computational arithmetic, arithmetic and logic unit, microprogramming.
- CA-III: memory organization and hierarchy, scalar and superscalar pipelines, multithreading support, multi/manycore processors, on-chip networks, parallel architectures, distributed and shared memory, heterogeneous architectures, and non-conventional architectures.

This paper focuses on Computer Architecture III once this author was/is the same professor for both CS and CE curricula. Remote activities can drive more abstractions and reduce the attention to hardware, which demands infrastructure in university labs, e.g., Field-Programmable Gate Array (FPGA) devices, Raspberry Pi boards, computer clusters, and others. Regardless of the online or in-person approach, simulators can give students more flexibility and, mainly, help them in learning. However, a group of students would like more than simulators.

It is important to highlight that this paper shows the usual dilemma for traditional undergraduate programs. Virtual labs with all infrastructure to remote access are not present in most universities, including PUC Minas. Thus, rethinking learning is crucial post-lockdown, when new technologies have been used to improve teaching in remote or hybrid disciplines. The following section describes characteristics and expectations related to in-person, remote, and hybrid approaches for a post-lockdown education in Computer Architecture.

IV. Educational Approaches

In this paper, educational approaches, i.e., materials and methods, cover three teaching/learning synergy options: strong, weak, and moderate. The idea is to define an inseparable relationship between teaching and learning as follows:

- In-person approach: strong connection.
- Remote approach: weak connection.
- Hybrid approach: moderate connection.

Subsections IV-A and IV-B present approaches developed from pre-lockdown to current days. Section IV-C presents our planning for a new approach to be implemented in the second semester of 2022.

A. In-person or Strong Connection

An in-person scenario is the most usual approach and is called outdated by some educators that insist on comparing different ages and technologies with the same methods. However, as previously discussed, learning can be improved by reactions and feelings. Therefore, if a student has a teacher or a colleague to ask, answer and argue with, he/she has a better learning environment. This last sentence is not related to a student using a computer connected to the Internet, e.g., to see, listen and speak because there are no suitable conditions for everyone, besides other limitations that we can discuss in the next section. This section discusses in-person practices and how they can establish a strong connection between teaching and learning.

Over the pre-lockdown years, we researched better practices to teach parallel computing [17]–[19]. All of them were based on in-person activities. The connection between students and teachers was strong since they were together in the same environment with the same purposes and objectives. It was possible to see and feel the interest, and consequently, if some students had more focus or not, or if part of them needed more attention from the teacher, regardless of theoretical or practical activities.

For this scenario, Computer Architecture III was/is based on the following approach:

- Two individual tests. They cover different contents totaling 55 points.
- One individual micro-test. It covers content from all disciplines already done, including CA-III, totaling 5 points.
- Two supervised work groups. The first one is about memory simulation using Amnesia Simulator [20], totaling 20 points. The last one is a simulator of Tomasulo's Algorithm [21] the students need to design, totaling 20 points.

All tests are individual and without access to any material. However, the two work groups need our attention because we can find answers related to the learning phase. Although teaching is relatively easy, the experience grows when the teacher understands the best learning approach.

As expected, work groups have at least one leader, and there is no reason for surprises. A leader is important because he/she can help/teach other students to learn, and those who teach also learn. Both work groups are supervised, and the activities occur at a laboratory for two or three weeks. Thus, the teacher is present to evaluate each group, give answers, and interact.

Unfortunately, this method was interrupted by the lockdown, and there is no comparable result to check its efficiency. However, student feedback was very significant. As a result, it was possible to verify learning gaps to teach again. In the end, the students handed in a draft paper for all memory assessments and a simulator of Tomasulo's Algorithm. For the last one, they could program in any language, and the results confirmed how a supervised practice could give the students better comprehension of this subject.

B. Remote or Weak Connection

A remote scenario has a weak connection between teaching and learning. Many technologies [22], [23] to support teachings, such as Zoom, Microsoft Teams, Canvas, and others, can help us a lot. However, this support is focused on teaching, and teachers are mature workers. When we look at the other side, we can find students. They are immature, most need a supervisor, and sometimes they create a wrong analogy between teaching and *download to brain*.

The Internet can reduce distances, and it increases independence or self-reliance. In general, these characteristics are suitable for everyone. However, they can guide us to an

incomplete education if we are immature in this knowledge-acquisition process. Perhaps, the worst problem is based on priority decisions about *when*, *what*, or *how* to study. This problem is also common when we have an in-person scenario. However, in this case, it is possible to supervise and identify, in part, how to solve it.

During the lockdown, Computer Architecture III was based on the following approach:

- Two individual tests. They cover different contents totaling 40 points.
- One individual micro-test. It covers content from all disciplines already done, including CA-III, totaling 5 points.
- Twenty individual tiny tests throughout the semester, totaling 20 points.
- Two work groups. The first one is about memory simulation using Amnesia Simulator [20], totaling 20 points. The last one is a simulator of Tomasulo's Algorithm [21] the students need to design, totaling 15 points.

Even if we can open cameras, considering that cameras can help us to solve remote learning, it is only possible to follow some students. Some of them can argue that they do not have cameras or that these cameras are not working, and sometimes, the Internet connection could be better. Moreover, if we have, e.g., 40 cameras working at the same time, it is possible to see faces and only. In other words, this remote environment is prepared to teach, i.e., one way. We need new technologies to help us to create a synergy, which means the perception of reactions and feelings. Probably, in a metaverse, we can find this possibility; however, this synergy is the same that we had in the first classrooms centuries ago because we are just going to change the technology, and the method will be the same.

Well, work groups are not supervised in this approach, and now we have twenty tiny individual tests. The idea is to create an engagement, but it is difficult because teachers are not on the other side to interact. Regarding education, engagement without interaction is the same as saying we have a lost connection. Now, it is important to highlight that interaction is not just answering questions but teachers need to be proactive, so they need to search for gaps without waiting for them. Anyway, the connection was not lost but weakened. It can be strong for mature students but weak for many immature students (most of them).

There is an advantage in this scenario: now students can organize their agenda by studying from home. However, what is the priority? Students lead with priorities to organize their workloads, but during the lockdown, with an economic crisis, this flexibility can be used to work at home. If learning concerns us, teachers, how can we create conditions to improve student maturity in this new era? Is it about being more aware of the teaching/learning synergy?

C. Hybrid or Moderate Connection

Regardless of the scenario, Computer Architecture III has 80 hours. For a hybrid approach, we have in-person and remote with 40 hours each. This approach is a proposal for some disciplines at PUC Minas, and CA-III must adapt its approach for this new post-lockdown education.

What is a moderate connection for a hybrid approach? As previously described, there is a connection between teaching and learning, which can be strong or weak according to how involved teachers and students are in their synergy. Thus, in a hybrid approach (moderate connection), we have both worlds, and we must be conscious of exploring the advantages of connection.

First of all, the task balance is a teacher's responsibility. It means we need to decide the activities for each approach. On the one hand, in-person activities are based on supervised work groups, individual tests, and teaching based on dialog. On the other hand, remote activities can be used for teaching (exposition and dialog). We know that teaching includes content exposition, but the dialog is necessary to bring students for a discussion, which is vital to their maturity. This dialog is more important in a hybrid approach because we need to create better conditions for student independence and self-reliance since part of the discipline will be remote. For this reason, in this approach, the students must be conscious of exploring the connections between teaching and learning.

In the second semester of 2022, this author will teach CA-III in hybrid (Computer Engineering), and in-person (Computer Science) approaches. The idea is to keep the same activities described in Subsection IV-A, but with a task balance for a hybrid approach as proposed in the previous paragraph. At the end of 2022, two different scenarios based on the same activities, but using different connection relationships, will be evaluated to understand how the synergy works between teacher and students.

V. Overall Discussion

Online technologies helped universities to keep their work during the lockdown. However, for learning, our experience, including related work, showed that teaching success only sometimes drives us to the same learning success. We can call this situation *false positive* when the most positive experiences in education during the COVID-19 lockdown related to teaching guide us to believe in the same learning success. For instance, according to Computer Architecture III, a comparison between the in-person and remote approaches shows that the average approvals are similar. However, the average grades are a little higher with the remote approach. In this author's view, and based on feedback from students and other professors, students enrolled in face-to-face courses show low learning in remote approaches, regardless of the higher grades, which are *false positives*. In addition, some students work in groups to solve individual tests, changing the perception of success in learning.

Students are *thermometers*, and their feedback is essential to understand how good online experiences were during the lockdown. At PUC Minas, most said the importance of returning to on-campus activities: "nothing compared to being in a classroom and socializing". Synergy is important, and we must

explore it for a high-level education. Based on their profiles, they know the best way to learn.

However, we have to think about flexibility. In other words, we can give the students more responsibilities to decide about *when*, *what*, and *how* to study based on more free slots in their agendas. A strong connection is good because it is strong, but we need to evaluate a moderate connection (hybrid approach) to understand its characteristics and educational achievements.

VI. Conclusions

There is no determinism in education, and we know there are many variables to impact a successful proposal. However, in a new post-lockdown world, it is impossible to close our eyes to new technologies supporting flexible work, including education. It is clear the advantages and disadvantages of all approaches. The in-person approach has a story to tell; during a lockdown, we received new experiences (online/remote approach) to tell two stories. Now, it is time to acquire new experiences, and the hybrid approach needs to tell its story.

The future work will evaluate the hybrid approach to understand questions and answers and how a moderate connection can explore the synergy between teaching and learning. We have a great opportunity, two equal disciplines but two different approaches.

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