SoC Architecture & Design

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INTRODUCTION

Distance or online education is pedagogically and fundamentally not different than in-person learning. The main difference is the tools available in the online context. Hence, it is important to elaborate the fundamental concepts of our course in general, and then specify the online aspects for the online course held this year. Whereas education is traditionally teaching-based, modern education theories emphasize on learning-based methods. That is, a student-centered approach where course leaders facilitate learning process of students (an active act by student) by fostering a growth environment, providing access to the necessary tools as well as support and guidance. This is in contrast with the traditional approaches where the course leaders teach the content to the students (a passive act by students) through frontal lectures, where students mainly memorize the content. Even though the teaching-based method may be effective for a certain (and rather limited) group of students, it is not the most suitable method for the majority of students as their learning pace, existing knowledge, and their capabilities is not taken into account, memory is volatile and internalization which is necessary to convert memorized concepts to learned concepts and skills are often skipped. Learning-based methods on the other hand come with a significantly larger workload for the course leaders and requires a wider range of skillset, preparedness, adabtability, agility and experience. Given the student-centric approach in learning-based methods, preparing a suitable growth and learning environment requires taking into account the wide range of knowledge, skills, needs, and capabilities of each and every student. Despite immense preparations, such an enviornment is highly dynamic and unpredictable, hence the leaders need to be prepared to assess the situation continuously and have the necessary agility to adapt the planned learning activities in responses to unforeseen circumstances. Moreover, they need to motivate student to go through the learning process and keep them engaged at all times, a difficult task which is rendered even harder in distance learning environments. In SoC Architecture & Design (385.156), we use a learning-based approach based on modern education theories. In the next section, we present the fundamental concepts of the used approach and in the section following it we discuss how these concepts were transferred to an online distance-learning environment. Finally, we conclude by answering contest-specific questions.

FUNDAMENTAL CONCEPTS

MINI-LESSONS

Learning requires students to be engaged, interested, focused and active at all times. However, this is a difficult task as studies show that for most people maintaining high levels of focus on a task or topic, such as required to learn it, for longer than 15-20 minutes can be quite challenging, and for some rather improbable if not impossible. Therefore, we break our sessions to a series of mini-lessons of 10-15 minutes each, during each of which a given sub-topic is concerned and a certain method and participatory activity is used. Changing activities and methodology, as well as theme and topic of learning allows the students to refresh their attention and be able to remain engaged and continuously participate in active learning.

BOPPPS MODEL

Each mini-lesson follows the Brige-in, Pre-test, Participatory-activity, Post-test, Summary or in short BOPPPS model. The entire session is also wrapped in a larger BOPPPS model, where each mini-lesson is practically the

participatory-activity part of the overarching BOPPPS implementation. In the following, we briefly explain each part of the BOPPPS model as we understand and use it. We note that even though usually the same order as below is used, the order is flexible and could be changed based on needs, or certain sections could be combined (e.g., post-test could serve as the summary of the mini-lesson).

BRIDGE-IN

We often start each (mini)lesson with a bridge-in. Bridge-in is the motivational part of each (mini)lesson. It provides the students with information on why the (sub)topic of each (mini)lesson is important and relevant. Why should they learn the content, where does it help them and how they can use them? This motivation could be new information or a question shared by the students or facilitators (course leaders) and it could be stemming from industry, history, personal experience, or other parts of the course (including previous sessions or lessons).

OBJECTIVE

In objective part we explicitly formulate what is the goal for the student in that (mini)lesson. That is, what are they supposed to learn (expected learning outcome) and what constitutes a successful learning experience. In order to enable students to self-assess their success in learning the expected learning objectives, it is not enough to explicitly mention the objectives, but this formulation should be clear and measurable by the students and from students point of view. To this end, we use verbs associated with a clear actions as opposed to conceptual verbs. E.g., „Today I teach you what is network on chip" is not from students point of view, and it is not clear and measurable by the students. They cannot assess when the may have accomplished the objective. Hence, we formulated part of this objective as „By the end of this session, you will be able to name at least two advantages of the network on chip technology". Students can thus self-assess and measure whether they have acommplished the expected learning objective and if not, to what extent have they approached it (e.g., I can name only one advantage, I need to learn at least one more). A well-formulated objective helps students to understand better the goal of (mini)lessons and identify the crucial points therein, maintain a better focus, and have a realistic understanding of their progress and status regarding the expected learning objectives. If possible, we try to maintain learning objectives visible to students at all time during the session to enable them to calibrate and self-assess the progress of the session and their own progress at all times.

PRE-TEST

Pre-test is a tool we use to assess the overall readiness of the class for the planned (mini)lesson. Therefore, its goal is to assess pre-existing knowledge of students or whether previous learning objectives required for the new (mini)lesson are met. Based on the outcome, we can and often do adjust the participatory activity or the entire (mini)lesson. For example, if the (majority of) students have existing knowledge regarding the topic and objective of the (mini)lesson, we can skip it or go over it very quickly. Alternatively, if they don't have pre-requisite knowledge, we add a (mini)lesson on the necessary pre-requisite knowledge before proceeding to the originally planned (mini)lesson. Hence, the objective of a pre-test is a rather informal assessment of the entire group. Moreover, it helps identifying students with more knowledge on the topic and those who need more help. This can help us in pairing and grouping process, where we pair students with more knowledge with students who can use more help. Sharing their knowledge with peers who need their help, keeps more knowledgeable students engaged instead of bored. Pre-test could be done by asking questions, provoking discussions, using quizzes, tests, ballots, or in online format using polls and online questionnairs and live feedback forms. We select the appropriate tool based on the specifics of the content or the conditions of the session (such as e.g., previous or planned future activities or tests).

PARTICIPATORY-ACTIVITY

This is the portion of each (mini)lesson where the main learning happens. In this portion, the students perform different activities that allows them to discover, learn, develop, share, and grasp new concepts and thus "learn"

the intended content while and by doing the activities. This activity should be engaging for each and every student and keep their interest and allow them to participate in the activity and development of the learning concept and experience. Therefore, we spend a substantial amount of time to devise these activities and fine tune or adjust them when necessary. We also try to use a diverse set of cognitive and motory activities to make sure students stay fresh and can maintain a high level of focus, necessary for an active learning. Moreover, when possible we alternate between activites that involve more cognitive or more motory actions, and if not possible or suitable, alternate between different types of cognitive (or motory) activities. That is, we avoid using the same type of participatory activity in two mini-lessons in a row. Various types of activities used in this course are detailed in the next subsection which is dedicated to participatory activities.

POST-TEST

Post-test in many ways is similar to pre-test with the main difference being the object of assessment. That is, in post-test, we assess the learning objective of the current (mini)lesson and whether they are reached (as opposed to assessing pre-requisites and existing knowledge). Therefore, we use similar methods for post-test as well and the outcome is then used to decide how to proceed with the session. That is, whether to continue to the next learning objective and mini-lesson or linger longer on the (sub)topic at hand.

SUMMARY

At the end of each (mini)lesson, we summarize the content of that (mini)lesson to ensure that all students receive a unifited overview of the activities as well as learning process and objectives. Moreover, the repetition of the content in a summarized format helps the concepts to settle in students mind, help their understanding, and find potential misunderstandings or unclear points about which they can pose a question to us, to the class, or their peers.

PARTICIPATORY ACTIVITIES

In this course, we use a large number of participatory activities, some of which are more generic and could be easily adopted by other course with little to no adaptation and some can provide an idea of possible activities which need a well-thought design to be used in other context. As discussed before, the participatory activity is where the main learning happens and students should learn actively by doing and engaging in the designed activity. Therefore, it is important to make sure that all students can actively participate in these activities and the activity can lead to intended learning objective. To this end, despite the well-thought and well-prepared activities, we had to refine them during repeated experiments of different years, or replace some of them with new ones. Here, we describe activities used in this course and their compatibility with distance learning tools.

VISUAL ACTIVITIES

In these activities, the students are asked to conduct a visual-motory activity using pens and paper. These activities often simulate or emulate what happends in real life and by doing it they face the challenges of those tasks in real life or can speculate and understand them. In some cases, they are asked to think and come up with solutions for those challenges. Having physically and visually faced those challenges often is a great help in their thinking process and coming up with more practical and realistic solutions. Some example of this kind of activity is creating random defect patterns on a (paper emulating) silicon wafer and study the relationship of these defects, the size of the chip they need to produce, and the final yield (number of healthy chips over total number of chips). Another example, is to emulate the processing steps of a Graphic Processing Unit (GPU) in a group in order to find out the bottleneck in speed and how they can improve that. A simpler example is connecting different terms with their potential definition and discussing their speculations. We ported these activities to a distance learning context using online whiteboards (e.g., AWWAPP) or using PDF of the papers and editing tools on their own personal computer, or using the quiz tool in TUWEL (for the matching of terms and their potential definitions). We could also aski the students to print out the papers, but we avoided that given that not all

students have a printer available to them. Therfore, the haptic experience of these activities is often lost in the distance learning platforms.

SMALL GROUP ACTIVITIES

In these activities, the students are divided into small groups to perform a small activity, which usually consists of solving a small problem, or conducting a directed discussion, or other small tasks. Breaking down the big class into very small groups of 2-4 students encourages the students to engage in the activity with high levels of concentration and using their own reasoning powers. Moreover, being among peers, it encourages them to more freely ask their peers questions they have in their minds or about the potential ambiguities they find in the topic. In addition, the explanation of their peers is often more effective since it has a closer language and level to their own level of understanding from the topic. For stronger students, helping other students keeps them engaged and active and provides a satisfactory feeling of being helpful to others. In addition, we monitor the activities in the groups and if need be provide the group with helpful hints to facilitate the activity and the learning process. Furthermore, we rotate students in different groups and help them improve their communication skills. In part, to create a motory movement and change of scenary for students which helps them to stretch and feel refereshed and in part to shuffle the knowledge level in different groups. In addition, these close interactions help the students to bond with other colleagues they didn't know before and hence expand their network, which is beneficial to them in the current course and the future of their career.

Zoom provides break-out sessions which are suitable for such small group activities online, however, again the motory advantage is lost. A highlight of this feature in Zoom is the broadcast function that helps communicate with all groups simultaneously. Moreover, the function to close breakout sessions and bring students back to the larger group is very helpful. Another important online tool here was AWWAPP which allowed the students to share their work using the free whiteboard while discussing and working on their task in their small groups.

SMALL GROUP TO LARGE GROUP KNOWLEDGE TRANSFER

Another important activity is bringing the knowlege or finidings of small group activities to the large group. In this activity, first each group presents their own finding. Often, we devise the tasks of each group slightly different so that their different (or sometimes seemingly contradictory) findings can provoke a new large group discussion and promote their thinking and learning, or so that the collection of small pieces of the puzzle solved by each group creates a bigger picture and leads to a secondary learning objective. In the latter case, the discussion of finding of each small group in the larger class group promotoes the reasoning and leads to the learning of the (larger) learning objective. At the end of such activities, we usually ask students to summarize the overall findings or summarize the findings ourselves. This activity can simply be transfered to online platforms such as Zoom.

BRAINSTORMING, CLASS DISCUSSIONS, QUESTION & ANSWER

Another set of participatory activities we use, which to some extent are more traditional, are activities with the entire class at-once, where questions are presented (from us or the students) and we try to find an answer together. When a question is presented by a student or us, we try to direct it to create an active group discussion or a brainstorming activity during which the students themselves arrive to the answer. However, it is important to supervise these activities to make sure everyone feels safe, the discussions are directed and heading the right direction, and everybody is at the end on the same page. As it often happens, some students arrive to the conclusions faster than others. In such cases, we try to create an active discussion between those who have arrived and the rest of the class. This helps the self-esteem of both groups of students and helps in maintaining students who have already arrived to the conclusions active and engaged while trying to explain the conclusions to their peers in their own language. These activities can be conducted online using Zoom or Gotomeeting. Live feedback tools such as Menti can facilitate inititation of the discussion by visual presentation of various view points and opinions in the group in an anonymous fashion, creating an initial starting point for discussions.

Moreover, the Zoom whiteboard feature is very helpful to write down the main points of the discussions and brainstorming activities to keeps a track of them and feed them back into discussions when necessary.

MOTORY ACTIVITIES/GAMES

Given that our course, similar to many others at TU Wien, are very heavy on the cognitive load, it is important to add motory activities or physical actions whenever possible. This helps the students to find a physical sense of freshness and prevents them from brooding and boredom. Further so, if these activites are encapsulated in a game format, which adds the excitement of playing too. In summary, these activities significantly contributes to maintaing a high level of focus and learning capacity. An example of these kind of activities is resource allocation practice using a physical radar chart, threads, cards, and dice. We could replace the resource allocation activity to a distance learning context by using everyday objects such as lentils, beans, or chickpeas the students had available to them and using bowls for different bins to which the resources (the food) would be allocated.

Another motory activity that we have devised is a Network on Chip emulator game, where students have to create different formations (representing various network topologies) to pass a certain number of cards (representing the information) from a source to a destination. Each group competes with others that have a different formation, and the activity and the result represent the advantages and disadvantages of different technologies. Again the excitement of the game and the physical movements makes sure that the students remain fresh, interested and engaged, while learning the new concepts in a memorable way.

Another motory activity, which is rather simpler, is to have (knowledge) stations where the student go to each station, read a piece of information or add their input to the sheet posted at the station, or discuss a topic at each station. This activity can be used to obtain anonymous feedback on students knowledge regarding the topic or promote thinking and provoke discussions among the students which can lead to learning. Another similar activity is distributing terms and definitions to students and asking them to find among each other the best match by moving around and asking who has which card. Even though, such activities could be performed otherwise too, here the motory activity (physical movement) is the highlight to refreshen the students and their moods. We replaced these activities by Menti live feedback or the quiz feature of TUWEL (for the matching activity), however, the motory advantages were lost.

SNOWBALL (PAPERBALL) GAME

This is one of the most popular participatory activities among students and very versatile for various concepts in the course. In this activity, the students write on a piece of paper the answer to a question which could inquire about their opinion or their existing knowledge. Then they crumble the paper and throw it to other colleagues repeatedly. Then students are asked to read and share what they find on the paperball they end up with. This way, we can learn about the overall class knowledge and opinion in an anonymous fashion without putting any student on a spot light. The safety of anonymity helps them to share their opinion or knowledge more freely. Moreover, each students will then think and reason (or can be explicitly asked to reason) about what they have received on their piece of paper. This provokes their reasoning engine, provokes open discussions and promotes their learning. Moreover, the motory action of crumbling and throwing the paper helps them to feel fresh and prevents their brooding and boredom. This participatory activity is good particularly for pre-test (or post-test) activities. Unfortunately, cannot be performed online. For online course we replaced it often by tools such as Menti live feedback forms, however, it loses the advantage of motory activity which can be physically refreshing.

QUIZZES

In the beginning of each session, we take a short (<5mins) quiz with usually one or two questions regarding the content of only the previous session. The quiz motivates students to review the content and their learning from the last session before the new session. This has few purposes and advantages. First, this review helps student to commit what they have learnd to their long term memory and internalized the learnings. Second and more

importantly, makes sure they have polished their learning and knowledge from the last session and now are ready to build up on that in the new session. Third, given that it contributes to their final mark, they have a more serious and critical look at the content and their learning and if there are any ambiguity, they will have the opportunity to bring it up and ask questions to have it resolved. Fourth, even though each quiz has a small role in the final mark, the total of all quizzes contributes to nearly half of their final mark, therefore this keeps them both motivated to take each quiz seriously and helps them to reduce the pressure on their final exam since they can create a good safety margin for themselves during the semester. This of course add to our workload as instructure since we need to devise and mark each quiz, however, it plays an important role in the quality of the education for students and hence we overtake it. Using online tools such as TUWEL quiz can help in this regard.

SAFE ENVIRONMENT

While learning happens outside one's comfort zone, it will not happen if students do not feel safe to step outside their comfort zone for learning, dare to guess, or speculate, analyze or make mistakes. Hence, other than explicti mention of the class being a safe environment and encouraging open discussions, asking question, sharing analyses, and speculations, we are extremely attentive to our own behavior as well as those of students to make sure everyone feels safe in the course environment and feels free to ask questions and share their thoughts.

FEEDBACK

The frequent pre-test and post-test provides us with indication on the quality, rate, and direction of learning experienced by the students in the course. However, to obtain more explicit knowledge about how the course is run, expectations of students, and adjust the course when needed, we conducted a short anonymous feedback session every 3 to 4 sessions. We then tried to incorporate what we could possibly incorporate from the feedback. Moreover, we had a follow up open discussion with the class to discuss feedback points that needed explanation, clarification, or more elaboration to either find a suitable practical solution or try to set the expectations right. This can be conducted online as well using various tools available.

DISTANCE LEARNING

In the distance learning format, all abovementioned concepts remain important, valid and critical. Hence, we strived to implement all of them as well as possible. The portion of the concept that is most affected is the participatory activity, in particular the motory activities. However, we tried to maintain –with adjustments- as many of the participatory activities as possible using everyday objects or online tools available to the students. Table 1 summarizes the tools we used and here we briefly present how they were integrated into our course. In the first session of the classes, together with the students we went through all used tools and rehearsed using them via mock-up activities. This ensured students are able to use them and will be familiar and comfortable enough with them during the rest of the course. However, that proved to be a smooth process since almost all the tools we had selected had a very intuitive and easy to use interface (maybe the main exception was TUWEL, however, most students had enough previous practice with it).

Zoom was the main tool used to create a virtual classroom. Zoom not only provided a medium for communication and sharing presentations and other contents, it helps us with smooth handling of discussions as well as questions and answers given buttons it has for this purpose. Moreover, its whiteboard feature served as a very helpful tool to track the progress and inputs or highlights of class discussions and brainstorming. We used the break-out session feature to group students into smaller groups for small group activities and discussions. Setting a deadline for break-out sessions helps keeping track of time and following timeplan of the course. Moreover, broadcasting feature allowed us to share complementary informatin and hints with all students in different groups (break-out sessions) in an efficient way and without visiting each group individually (which was possible too and we used it mainly to monitor and help with the discussions and tasks in each group). Zoom also facilitated conducting live pre-tests and post-tests by its poll feature which allowed us to ask students questions that helped us assess their level of knowledge or quality of learning and when needed share it with them. Lastly, it allowed

us to record the sessions in video and audio format (for those who do not have necessary bandwidth to use videos) and share them with the students using several security features. After obtaining students consent using the polling feature, we recorded the videos, and their embedded link was shared on TUWEL. Downloading feature was disabled through Zoom website and the students had to have a password to watch the videos and register before getting access to each video. Lastly, using the respective Zoom feature, we set a 7 days deadline for accessing the videos after the date each video was shared. All this, hightened the security of the recordings and students data. In summary, Zoom was the most frequently used tool for the course.

TUWEL was the main tool to communicate with students offline and provided them with the material, links, videos and other information they needed. We also used it for conducting the quizzes at the beginning of each session. Even though it has certain limitations and it took extra effort to import quizzes to the TUWEL environment, in total –especially in long term- we believe that it can save us time in marking quizzes and creating different versions of quizzes, or personalization of the quizzes, by using random generation of quizzes. Hence, we plan to integrate this also for in-person courses next years. We occasionally used TUWEL for some participatory activities too, such as connecting terms and their definitions, in particular when other tools did not support the typ of activity that we intended. The main point for imporvement is the user interface of TUWEL (especially for teachers) and the visual appeal of it (especially for students).

Another tool that we frequently used was Menti, which allowed us to assess students knowledge and create live feedback for students in various visually appealing formats. Hence Menti was heavily used for pre-test and post-test assessment of the students, form the initial core for discussions (here, the word-cloud feature was particularly helpful), or for certain participatory activities such as sharing their opinion by ranking different items in the discussion topic of the course or their findings from the small group activities. The anonymous results would be then shared live in an intuitive and appealing visual format with students.

We used AWWAPP for small group activities (so that students could share with eachother their works during the small group activities and discussions) as well as some participatory activities, especillay the visual activites. We used Typeform for informal anonymous feedback during the course and everyday objects students had at home to create some participatory activities with more motory and haptic engagement.

We could successfully transfer most of activities to a similar/equivalent online version, some of them with more adjustments and effort. A few of them, especially those conating a stronger motory portion, could not be transformed to online version and had to be replaced with other activities that could be performed online. Given that in the distance learning context most often motory activites are not possible, keeping students engaged and attentive was one of the hardest challenges of the online course. Here, we found frequent change of activity types, incorporating more fun activities (with game-like feelings) and visual appeal of the used tools the most helpful techniques to keep students engaged.

CONTEST QUESTIONS

WHICH TECHNICAL AIDS AND TOOLS WERE USED?

In order to support the online course, maintain students engaged, and provide them an interactive and safe environment which as closely as possible resembles an in-person course, several tools were used for different purposes. Table 1 summarizes these tools, their frequency of usage and their highlights.

Table 1. Technical assistive tools that we used for distance learning

Tool	Purpose	Usage Frequency	Highlights
TUWEL	To communicate with students such as posting necessary information (notices, links, documents, slides, videos), sharing their (partial) grades, holding online quizzes at every session, and occasionally for in-class activities (using quiz features)	Continuously, Every session	Quizzes
Zoom	To hold lecture sessions, share slides, communicate the course material with the students, ask/answer questions (students can raise hands using a button to prompt their wish for asking a question, without interrupting the session), poll student pre-existing knowledge (pre-test), poll to assess their learning at the session (post-test), hold breakout sessions for small group works, whiteboard to facilitate and document brainstorming, big group discussions and big group activities, recording each session for students post-class revisit with many security features	Every session	Polling, Break-out Sessions, Feedback buttons (e.g., raising hands for questions), White board, Security features for videos
Mentimeter (Menti)	To create appealing live (anonymous) feedback environment and in-class activities. Menti allows students to share their knowledge (existing or learned) or guesses with the classroom in an anonymous safe format, while receiving live visually appealing feedback in different designs suitable for the type of the question/activity and the expected outcome. Hence a suitable tool for pre-test and post-test activities, assessing knowledge and reacting (correction and/or confirmation)	Every session	Numerous appealing live feedback formats (e.g., word cloud, bar chart, scaling, ranking, etc.)
AWWAPP	Free whiteboard application for students to share their works (e.g., calculations) during group activities (particularly in small break-out sessions) as well as for certain visual in-class activities	Whenever needed (approximately in 40-50% of sessions)	Multi-user free whiteboard
Typeform	To receive anonymous feedback using an intuitive, visually appealing tool, about the content and conducting methods of the course and adjust accordingly. The tool has different modes of representing the results, which helps understanding the outcome for the teachers. The visual appeal also keeps student engaged during the feedback process.	Every 3 to 4 sessions	Good user interface (both teachers & students side)
Everyday Objects	For certain activities, everyday objects (beans, lentils, threads, pen, paper, …) were used to create a haptic feeling for the students and engage them physically with the activity and concept they work on	Whenever needed (on a few occasions)	Physical engagement, Haptic feelings

HOW DID YOU COMMUNICATE WITH THE STUDENTS? WHICH CHANNELS WERE USED?

TUWEL was the main channel for offline communication. More important news were shared via TISS as well. For online communication, we used Zoom to hold the sessions. The sessions were recorded (after obtaining all students' consent at the beginning of each session) and the recorded sessions were posted on TUWEL. To maximize the safety and security of the data, accessing the videos required a password (not posted on TUWEL for security reasons and shared with students only directly), and email registration by the students accessing them. Downloading feature was disabled in Zoom and the videos were available for only one week after each respective session.

IN YOUR OPINION, WHAT WAS THE MOST POPULAR WITH THE STUDENTS?

According to the feedback we received, students particularly enjoyed the most the interactive and engaging mode of conducting the course, rich with several entertaining participatory activities. The safe and open environment of the (virtual) class where they were welcome to ask all their questions and share their opinions, thoughts and concerns was another popular aspect of the class. Modern teaching methodology, thought-through usage of various innovative tools, transparency, student-oriented learning (learning by doing) were other positive aspects popular with the students. Balancing hands-on and theory portion in the course and using real-life relevant examples were other popular features with students.

WHAT COULD BE IMPROVED IN THE FUTURE AND ARE THERE AREAS IN WHICH YOU WOULD NEED SUPPORT?

Given the type of interaction with students using online tools communication needs to be more polished and explicit to avoid confusions and misunderstandings. It turned out that the same instructions (e.g., for certain activites, or quizzes) that have been used in previous years and polished accordingly and appeared non-problematic in in-person course, were still confusing and not clear-enough for students in the distance learning course. Hence, after early identification of this problem, we enhanced the communications and continously monitored its efficacy and ask students' feedback in that regard.

The definite time of break-out sessions could be sometimes stressful for certain (groups of) students. We identified this problem early on and tried to mitigate this by giving an extra long time for break out sessions and assess suitable closing time based on the progress of different groups and announce closing of the sessions in advance using the broadcast feature of Zoom.

TUWEL also has a large room for improvement, in particular regarding its interface, lack of intuitivity and visual appeal. Sometimes it takes unnecessary too long a time to do something in TUWEL, even though it may be very small, since it cannot be done intuitively or straight forward. Moreover, some actions are not supported, for example, the type of quizzes could be expanded (here also the tool is extremely counter intuitive). Moreover, support for other type of (participatory) activities, especially those that are conducted live would be helpful so that students don't need to learn and use many different tools. Even though that is less urgent since we managed to find superior tools with practically no learning curve for usage. Moreover, TUWEL seems complex enough already.

WHICH ELEMENTS OF THE CONCEPT COULD ALSO BE TRANSFERRED TO OTHER COURSES?

The concepts, methodology, and tools used in this course are independent of the course content. Therefore, they can be appropriated and used in virtually any other course of a similar type, that is, VO and VU courses, in any discipline. For laboratory courses, however, a more substantial change may be necessary to adapt the concepts to the practical requirements of the experiments and respective syllabus. Moreover, the parts that are more theory-centered might carry less weight in favor of creating more room for hands-on, practice-centered activities and experiments in laboratory courses.

WHO WAS INVOLVED IN THE CONCEPTION?

Dr. Taherinejad is the main person in charge of the SoC Architecture and Design (also in charge of SoC Module in Embedded Systems MSc program), who developed the main concepts and methodology used in the course. The content is developed by both Dr. Taherinejad (90%) and Dr. Krieg (10%, giving a guest lecture on hardware security).

OUTLINE OF COURSE CONTENT

In this course, students learn the key factors in designing VLSI circuits for System on Chips (SoC). The focus of the course is on the principles and theories. I developed this new course in 2015 for the new module of Systems-on-Chip for the new curriculum, Master of Embedded Systems, and taught in 2016 for the first time. For this course I have been nominated for "Best Lecture Award" in 2017, 2018, 2019, and 2020 as well as "Best Teacher Award" in 2018, 2019, and 2020. The outline is as follows:

- Introduction & Basics of SoC
- Chip Basics & Floor planning
- SoC Design trade-offs: Performance
- Processing cores & IPs
- Reconfiguration
- GPU architectures
- Approximate Computing
- Memory Architecture and Technology
- In-memory Computation
- Interconnects
- Cyber-Physical Systems-on-Chip & Self-awareness
- Hardware Security (by guest lecturer Mr. Christian Krieg)