

COMPETENCE-ORIENTED EXAMS USING VIRTUAL DESKTOP INFRASTRUCTURE (VDI)

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A description of a general concept for exams using VDI and Safe exam Browser (SEB), including process descriptions for planning and conducting such exams. The document includes checklists and technical details on how to configure and use VDI with SEB.



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1. INTRODUCTION

Today IT permeates our daily lives and, more importantly, our working environments, and has done so for several decades. Many if not most modern day work processes are defined, facilitated or enhanced with the use of IT tools – be they in design, research, communication or management. In light of this, an increasing number of lectures at higher education institutions have learning objectives that involve some level of competence in the use of specific IT tools (such as programming environments, CAD, simulation, or statistics software), as well as the successful application of the concepts on the IT tools behind them. Since it is good examination practice to measure any competence as directly as possible, the corresponding exams should take place at the computer.

Such competence-oriented exams offer a wide range of advantages over more abstract or more theoretical exam setups. They usually make a valid assessment of student competences easier. Good exam tasks are easier to design and easier to grade. Competence oriented exams improve students' learning motivation, as well as their perception of the relevance and fairness of an exam. Finally, competence oriented exams usually do a better job of making students focus on acquiring relevant skills, rather than mere rote learning “for the test”.

However, performing exams on computers requires some mechanism, which only allows selective access to tools. For example, students should typically not be able to access the internet and communicate during an exam. In this document, we provide a basic outline of how to create such an environment using a combination of Safe Exam Browser (SEB), virtual desktop infrastructure (VDI), and a learning management system (LMS). We successfully developed, implemented, and tested this environment at ETH over the course of the year 2012, and have now transitioned it over the years to an institution wide, freely available IT service. We would like to share the experiences and knowledge we were able to gather. We are convinced of our environment's advantages over other solutions, based on its reliability, scalability, adaptability, easy customization, and the comparatively low complexity and labor intensity of maintaining the service.



Image 1: Our second largest exam room (HG G1) with 170 computers; the largest (ONA E7) has 260 computers.

2. CONCEPTS

2.1. ORGANIZATIONAL CONCEPTS AND REQUIREMENTS

Before starting any VDI exam project, you should already have conducted some digital exams using SEB¹ and your LMS (e.g. Moodle, ILIAS, OLAT, etc.). You need this experience first, or otherwise you will not be able to minimize the risks and will have no backup solution if anything goes wrong.

You should have a suitable exam as your first VDI exam. The test should reflect the work students did during the semester. For example, it is possible to do an exam with Matlab if the students worked with Matlab during the lectures, but doing so is not feasible if the students have never worked with Matlab before. The number of students taking the exam should also be moderate: fewer than 50 for a first try are enough.

You should define your VDI service organizationally secured with service level agreements (SLAs) and operational level agreements (OLAs). If anything happens during the first VDI exams, it would be rather catastrophic for the whole proposition. If you cannot trust the people behind the infrastructure, you should not consider VDI exams.

Finally, you have to decide how many people you need for a VDI exam and what their roles are:

- You need a leader who takes the overall responsibility and who decides what happens if something goes wrong.
- You need one or two people to provide first level technical support and exam-related support during the exams.
- You need persons with a highly technical background for major problems and for monitoring the whole system during the exam.

2.2. TECHNICAL CONCEPTS AND REQUIREMENTS

A virtual desktop infrastructure enables you to provide secure exams with any application via a highly customizable setup.

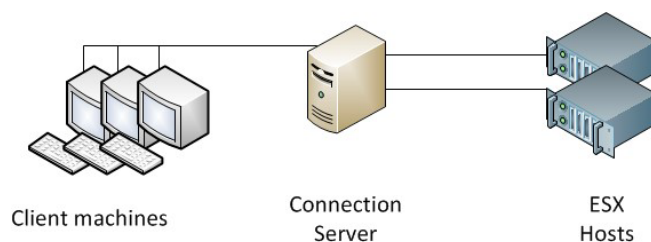


Image 2: Structure of physical machines

We have four physical components in our environment:

- The client machines are Windows 10 desktop PCs. At ETH, on one hand the University owned PCs in the student working rooms are used and on the other rooms will be equipped extra with hardware for exams only. However, it is also possible to use notebooks, tablets (Android, iOS, Windows 8.1/ RT and Windows 10) or Linux based machines.
- The connection server is the single point of contact for all the client machines. It redirects physical machines to corresponding virtual machines.
- Our ESX hosts are extremely fast servers. All our virtual machines (in principle up to 900) run on them.
- The fourth hardware component is our strong and partially redundant gigabit network.

¹<http://safeexambrowser.org/>

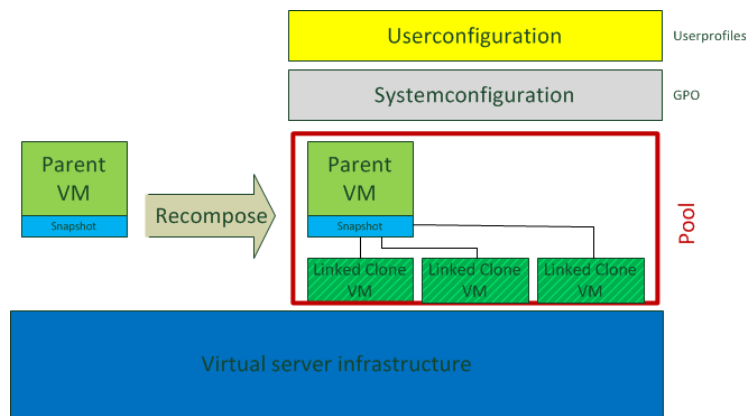


Image 3: Configuration of our setup

Image 3 shows the different layers of the setup. We have the underlying infrastructure running and create a Parent VM, which is the basis for every other parent and VM. This parent is a clean Windows 10 environment with all updates, all drivers and with all additional software we use in all the different exams. The parent VM in the pool is a clone of the first parent, but only with the software or applications permitted by SEB because we need these applications for the special examination setup. Therefore, for each exam we clone the first parent, define in SEB the application used for the exam and do set up a testing-pool of VDI-clients from this second parent for the testing before the specific exam.

Before the start of an exam, we check these VDI-clients by testing them, bringing them up to date and making small changes according to the exact setup required. After testing we deploy a new image of the parent to the needed number of machines (linked clones), and are ready for the exam.

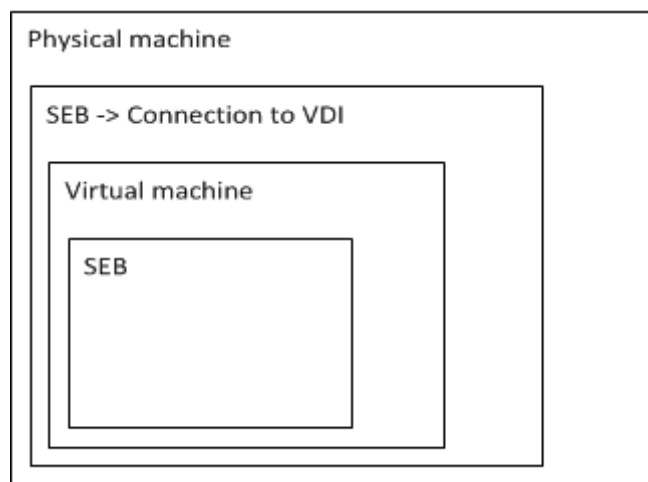


Image 4: Structure of VDI examinations

Image 4 shows the layers during an exam. The physical machines starts by script automatically, using the login of our special exam accounts. Then, the kiosk mode of SEB starts, which itself starts the VDI connector to the virtual machines. This VDI connector logs in using the same account as the physical machine. Moreover, each account connects with one VDI-client, on which a regular SEB with all the needed applications starts automatically.

2.2.1. A WORKING VIRTUAL DESKTOP INFRASTRUCTURE

An operational virtual desktop infrastructure is the most basic requirement for the successful implementation of the recommendations provided here. Installing, using and maintaining such an environment require a certain level of technical competence, which cannot be achieved by reading this document. Here we provide concepts and technical solutions, which are more or less independent of the VDI vendor. It should work with major virtualization applications such as VMWare, Citrix and Microsoft VDI.

Before implementing the exam setup, you should perform a clean Windows 10 installation. Use that as a master image.

- ☐ Have a VDI environment running.
- ☐ Have a master image with a clean Windows 10 installation (updates and drivers installed).

2.2.2. A SOLID NETWORK

Virtual desktops have a big impact on your network, as they send a huge number of images across it. A gigabit network is required; do not try to work with anything slower.

- ☐ Have a solid and working network.
- ☐ Have talked to the network administration about the capabilities of your network.

2.2.3. ENOUGH PHYSICAL MACHINES

One virtual machine needs one physical machine. You should have about five to ten percent spare machines (physical and virtual).

- ☐ Have checked your infrastructure and have enough working physical machines.

2.2.4. EVERYTHING ELSE

For different VDI setups, you need different applications, licenses and configurations. This description is not a part of the document.

The checklist in the Appendix provides you with an overview and examples of what is possible in such an environment.

- ☐ Know exactly what sort of exam you want to provide.
- ☐ Know exactly what you do need and what you do not want.

3. TECHNICAL DOCUMENTATION

3.1. SETUP

Type	What we currently use
Physical servers	2x8 ESXi Hosts HPE ProliantDL385, Processors 2048, 32TB Memory
Operating system (servers)	VMWare ESXi 8.8
Operating system (physical clients)	Windows 10 Enterprise x64
Operating system (virtual clients)	Windows 10 Enterprise x64
Connection software	VMWare View 8.8.1
Session-recording software	ObserveIT Enterprise 7.12.4 running on Microsoft Windows Server 2019 x64 with SQL-Server 2017.

Please note that these are neither requirements nor recommendations. It is possible to build the same setup using free and open-source software. It should also work if you are already using other virtualization systems like Microsoft Hyper-V and adapt the given concept to it.

3.1.1. INSTALLATION OF APPLICATIONS

Applications can be installed in the same way as on regular computers, but you should always consider that you are working on a virtual environment and that you are going to deploy this installation “as is” to students in an exam situation.

Our best practices are:

- Install all applications before securing the environment, because some settings could cause side effects.
- Do not install the applications with default settings (some of them can be globally configured through the installation wizard).
- Install only the required applications and choose them wisely. For example, it is not very useful to install Microsoft Office and Libre Office at the same time, except where students need to be able to choose their desired office suite.
- Use the same applications and version the students used during the semester.
- Use as many settings as possible that the students used during the semester.
- Make regular snapshots of the image and go back if necessary.

3.1.2. SECURING THE ENVIRONMENT

3.1.2.1. SECURING THE NETWORK

By securing the network, we want to achieve two things:

- 1) Students should not be able to access resources in the LAN or WAN which are not approved by us.
- 2) Intruders should not be able to access our virtual machines from outside the designated exam rooms: We do not want them taking the exams.

To achieve the first goal, proceed by creating a list of resources, which the students should or should not be able to access.

Website / Hostname	IP-Address	Allow / Block
www.example.com	192.0.43.10	Block
www.ethz.ch	129.132.128.139	Allow

Be sure to put all network resources on this list, i.e. your DNS server, your AD server, your LMS server, etc. If your list is finished, you should be able to decide, if a whitelist or a blacklist system would be more suitable for you.

Implementation of a whitelist or blacklist might be based on a proxy server such as Squid²; this is the technically best solution, as it enables you to update certain blocking rules during the exam, which is impossible if the solution is running on each virtual machine. If you are not able to determine a website's host name or IP-address, try using a tool like Wireshark³. If you use a single login/single sign-on solution like Shibboleth, you have to allow those login sites too.

Client-side network security solutions can be achieved by using various kinds of youth protection software⁴, such as Microsoft Family Safety⁵ or the Internet Explorer Rating-System⁶. We cannot really recommend those solutions, as you lose partial control over the system, but they are the easiest and cheapest ways to achieve certain results.

The second goal can be achieved by disabling RDP connections, disabling/blocking all non-necessary ports and disallowing the installation of software to default users. If your competence-oriented exam gives the users, the ability to develop software you may need to use session recording software, because it is an easy task to develop some sort of "chat application".

If possible, try to block all access to your exam LMS from outside the exam room, for example by limiting the system to certain IP addresses during the exam.

3.1.2.2. SECURING THE VIRTUAL MACHINES

Securing virtual machines is an easy but time-consuming task. Follow these steps for a maximum of security.

1. Uninstall all non-necessary applications.

Every non-necessary application on your virtual machine is a potential threat. When we installed our system, we uninstalled nearly everything through *appwiz.cpl* (Programs and Features), and disabled all non-required

² <http://www.squid-cache.org/>

³ <http://www.wireshark.org/>

⁴ http://en.wikipedia.org/wiki/List_of_content-control_software

⁵ http://en.wikipedia.org/wiki/Microsoft_Family_Safety

⁶ http://www.ehow.com/how_7209928_whitelist-microsoft-internet-explorer.html

Windows features like the XPS Viewer or the Windows Media Player.

Another way to disable certain features is to disable the appropriate service in *services.msc*.

2. Use Group Policies to disable as many functions as possible.

Group Policy Objects (GPOs) are another way to disable certain functions and graphical elements. This task takes quite a while, as there are thousands of different settings.

There is an incomplete list of our Group Policies in the Appendix.

3. Use session-recording software.

Session-recording software takes screenshots of the virtual desktops every few seconds. Please see 3.1.2.4 for a more detailed explanation.

3.1.2.3. SECURING OF APPLICATIONS

There are several flaws in modern applications running in a secure exam environment. They sometimes have too much functionality. For example, Matlab includes nearly complete web browser functions. Most applications also include some sort of online help browser. You have to disallow such functions in every installed application, if you want a truly sealed exam environment. The first step is always to identify which functions should not be allowed, and then to take the necessary steps to remove them. Most unwanted functionality is network related and can be blocked easily. Other functionality has to be “removed” by telling the students not to use it. Since we have a session-recording tool, we are able to make a spot check.

3.1.2.4. SESSION RECORDING

Using session-recording software is part of securing the exam process as a whole. It also offers valuable didactical metadata on how individual students conduct their exams. Our session-recording software takes screenshots every two seconds or after a few actions (mouse or keyboard). The software automatically places tags and metadata in the images. These metadata, which include values on opened applications, opened files or running processes, can be searched and viewed during and after an exam. We record exam sessions for three main reasons. The first and more important is that we are able to reproduce the exam in case of an appeal. This is beneficial not only for us but also for students, as they know they can prove certain things. The second reason is that we are able to view the last minutes of a student’s work during an exam. If one of the virtual machines crashes, we can examine what made the machine crash and fix this in later exams. The third reason is obviously to prevent cheating. However, as you might think, with the session recording you only identify cheating attempts, which are made inside the VDI environment.

The use of session-recording software is a great option for several reasons, but it must be handled with care:

- 1) It is essential to respect data-privacy laws, exam regulations and all other edicts. Check these carefully with your institution’s legal office in advance.
- 2) Huge impact on hardware: most enterprise session-recording software puts high pressure on servers and the network.

For example if we have an exam with 50 students that lasts 60 minutes, the application generates at least 90,000 screenshots with about 15-20KB per image. It also generates a few hundred MB metadata and logs.

3.1.3. TESTING

Testing is one of the key steps in a successful VDI exam.

- Always test your VDI exam the way the students are going to sit it: same room, same hardware and the same account policies.
- Test early and often.
- Document your testing (every error and every flaw).
- Create testing procedures and try to automate them (if possible).
- Do hardware tests too.

A potential testing-process could look like this:

- 1) Log in to the physical machine.
- 2) Log in to VDI through SEB.
- 3) Start SEB in the VDI environment.
- 4) Start an exam in your LMS.
- 5) Start and test all allowed applications.
- 6) Try accessing web-resources, which are allowed or blocked.
If you are using a whitelist ---> try all allowed resources.
- 7) Try the mechanics of your exam, like uploading files.
- 8) Log out of the exam, the virtual machine etc.

The next two points should be tested according to your needs. We highly recommend doing so before setting up an exam.

- 1) Try breaking out of the secure environment. There is no best practice for this and you will never know if you have eliminated all vulnerabilities.**

Most of the security breaches we discovered could be fixed by following these instructions.

2) Do load testing

Before we started the VDI exam, we performed huge load tests, to tell how many students can work in the environment at the same time.

We tested the CPU by running a stress test on 620 virtual machines. We tested the I/O performance by running a sequential and random read/write test on 620 virtual machines. We tested the network and graphics performance by streaming high-definition videos from youtube.com on 50 virtual machines. Later in the project, we redid this on 150 virtual machines.

We compared our results with the results of a standard physical machine.

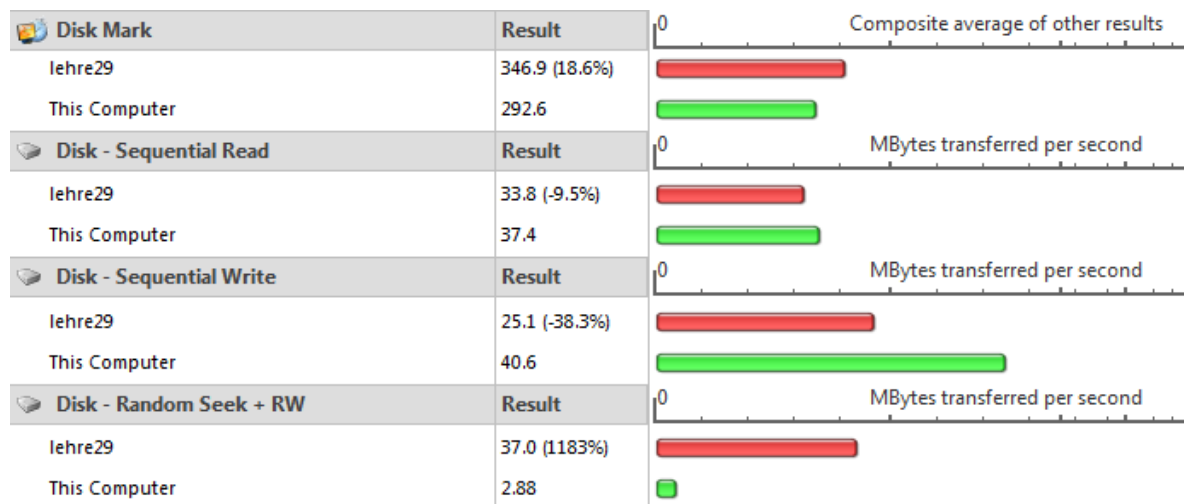


Image 5: Disk benchmark. The red bar is the virtual machine; the green bar is the physical machine.

3.1.4. ENHANCING THE ENVIRONMENT

After your first few exams, you should be able to identify possibilities for enhancing and improving your exams. Listen carefully to the input of students and professors.

We changed a few things after our first exams:

- We allowed different input languages after students asked for them.
- We disabled many unnecessary buttons in windows, for example favorites and libraries.
- We automated the login process as much as possible by using automatic starts and scripts.
- We removed the “first-run-wizard” in Microsoft Office.
- We assigned applications to more corresponding suffixes (.m -> Matlab and .M -> Matlab)

4. EXAMPLE CASE: VDI EXAM WITH MATLAB

This case study is based on a VDI exam we are conducting since about ten years. The assessment scenario of that exam was based on essay questions, and programming tasks in MATLAB with files uploaded to Moodle. The students had to load file-templates into MATLAB, and solve tasks, such as identifying and correcting coding errors, completing existing code or writing new routines. The students then uploaded edited files into the Moodle exam.

The virtual desktop features an installation of SEB 3.4.1, Matlab R2022a and a folder with the exam files.

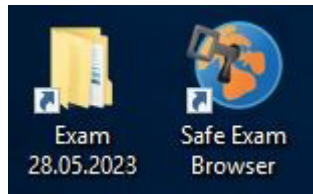
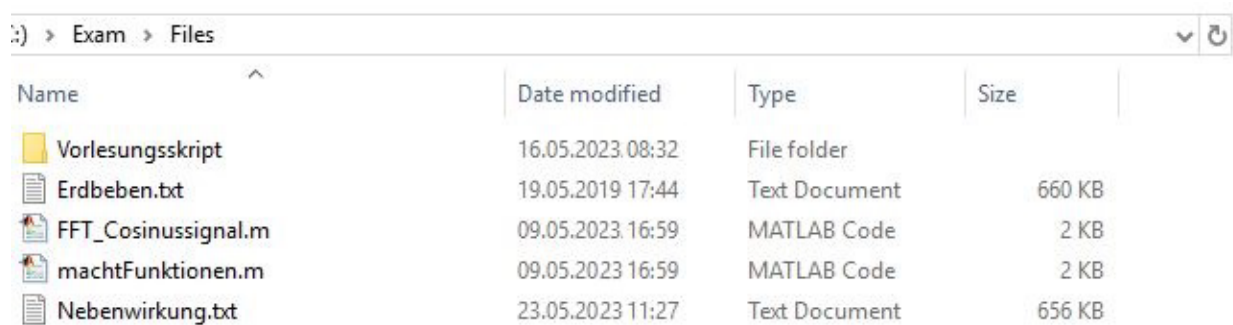


Image 6: A part of the icons on our virtual desktops

The image is a screenshot of a file explorer window. The address bar shows the path ':.) > Exam > Files'. The table below lists the files and folders in the 'Exam' folder.

Name	Date modified	Type	Size
Vorlesungsskript	16.05.2023 08:32	File folder	
Erdbeben.txt	19.05.2019 17:44	Text Document	660 KB
FFT_Cosinussignal.m	09.05.2023 16:59	MATLAB Code	2 KB
machtFunktionen.m	09.05.2023 16:59	MATLAB Code	2 KB
Nebenwirkung.txt	23.05.2023 11:27	Text Document	656 KB

Image 7: Example of a list of files for an exam

In the exam folder there is a read-only folder called “backups” which contains the same files as seen in Image 7. If a student wants to re-access the original exam files, it is possible through this backup folder. In the Exam – Files folder the students have the full read and write permission, so they can easily use these files.

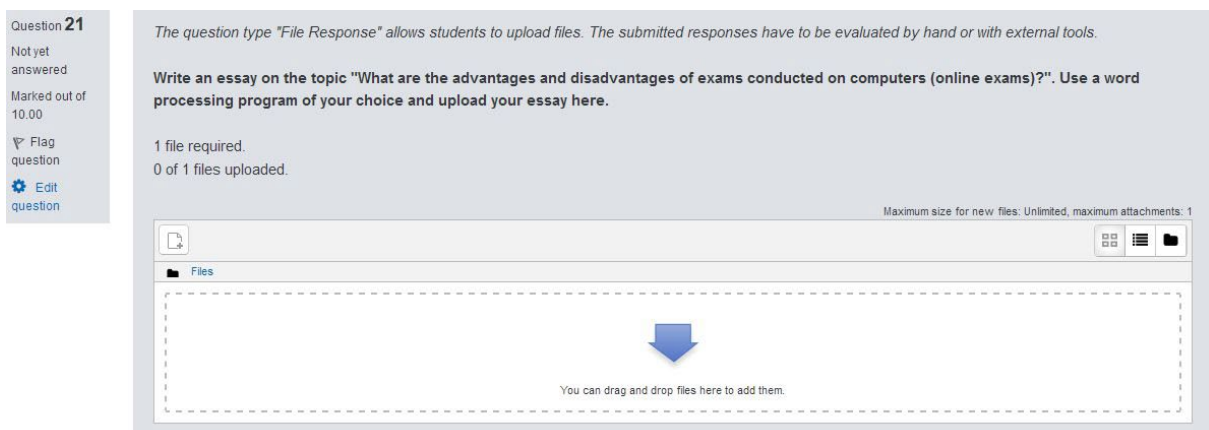


Image 8: Upload of files into our LMS

As mentioned earlier, the edited files had to be uploaded into our LMS. It is possible to re-upload and delete already uploaded files. Directly after the exam, IT-Support checks, whether all files have been correctly uploaded. These files are later made available to the people who correct the exam.

We have conducted similar exams from the beginning of the pilot project in 2012 since now. We are therefore very familiar with the process.

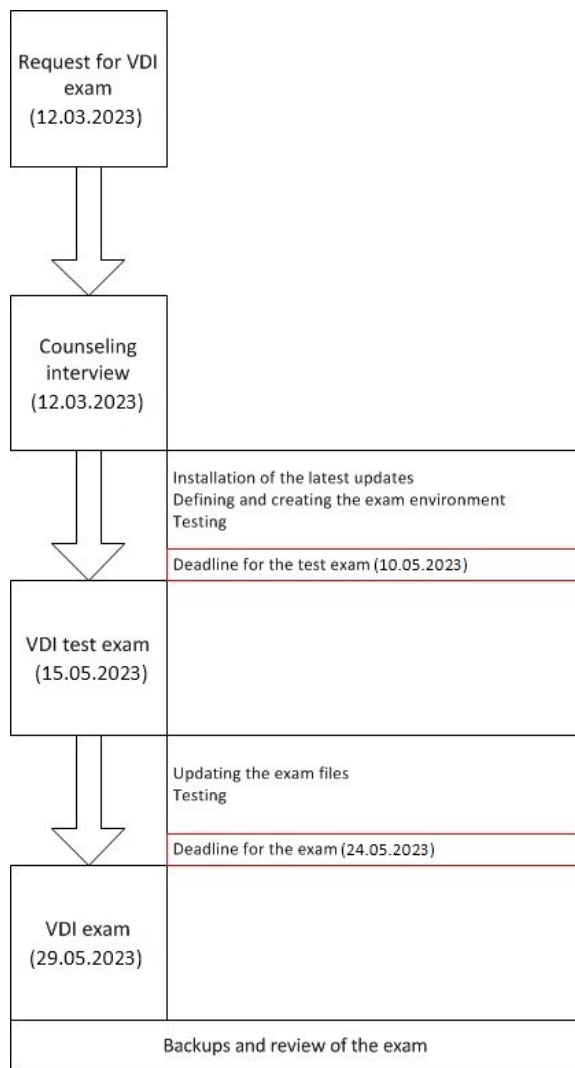


Image 9: VDI exam process

Usually, the first step after receiving the request is a guidance interview, which is followed by dozens of emails and telephone calls. During the guidance interview, the professors are informed on technical & organizational possibilities and defined follow-up tasks. The emails and calls concern the definitive exam setup.

The technical team perform their regular tasks, such as updating the environment, placing the correct exam files in the correct place (and later replacing them with the real exam files).

For a new VDI exam, we propose two major deadlines, the first one 5 days before a test exam, the second one 5 days before the real exam. As mentioned in the organizational concept, we always have a backup plan should we be unable to meet these deadlines.

During the exam, two system administrators are present, one in our office and one in the computer room. The first is responsible for the LMS and the host servers, and the second is in the room where the exam takes place. Here he provides second level support if anything unusual would happen on the machines.

Usually everything goes well, so after the exam, which can last from 1.5 to 4 hours, we only have to take backups and stop the virtual machines.

5. APPENDIX

5.1. CHECKLISTS

5.1.1. PREPARATIONS BEFORE THE EXAM

Identify any regulatory needs before thinking about doing VDI exams.

Technical VDI setup

Type	Product
Physical servers	
Operating system (servers)	
Operating system (physical clients)	
Operating system (virtual clients)	
Connection software	

Impact on the following resources

Resource	Check if talked to the responsible person
Network	
Physical servers	
Physical clients	

Role definition

Role	Check if defined
Leader	
Technical leader	
Exam support	

Exam setup possibilities

Item	Details	Yes / No
Access to the students home directory		
Access to exam files		
Access to different websites	Specify the FQDN ¹¹ or the direct link to the website	
Access to network drives	Specify the full path, also this path needs correct Permissions	
Access to Microsoft applications	E.g. Notepad, Calculator, Explorer, Paint, Office, Internet Explorer,	
Access to 3 rd -party applications	E.g. Adobe Reader/Acrobat, Matlab, R-Studio, SPSS, Databases (MySQL, PostgreSQL)	
Use of a session-recording-tool		

¹¹ https://en.wikipedia.org/wiki/Fully_qualified_domain_name
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Securing the environment and the applications

Action	Check if done
Uninstall all non-necessary applications	
Configure applications according to your needs	
Use GPOs to disable as many functions as possible	
Use session-recording software	

At the end, test your setup completely and try to eliminate potential security breaches. Identify design flaws and make the setup as easy as possible to use.

5.1.2. DURING THE EXAM

Action	Role
Provide exam support	Exam support
Provide technical exam support	Exam support
Monitor all applications	Technical support
Responsible person for the exam	Professor / Leader
Communication	Leader
Identify new requirements and changes	All
Document problems	All

5.1.3. AFTER THE EXAM

Action
Backup LMS, Backup VDI, Backup exam
Review of the exam
Implementation of changes