

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 been doing so for over a decade at the very least. Many if not most modern day work processes are defined, facilitated or enhanced through 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 large exam room (HG G1) with 170 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; 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. It should be aligned with 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.

Your VDI service should be defined and 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 can't trust the people behind the infrastructure, you shouldn't consider VDI exams.

Last but not least, 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 someone with a highly technical background for major problems and to monitor 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.

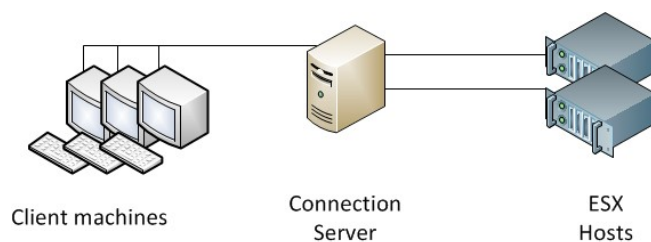


Image 2: Structure of physical machines

We have four physical components in our environment:

- Client machines: These are regular Windows 7 desktop pcs, but it's 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 (up to 300) run on them.
- The fourth hardware component is our strong and partially redundant gigabit network.

¹<http://safeexambrowser.org/>

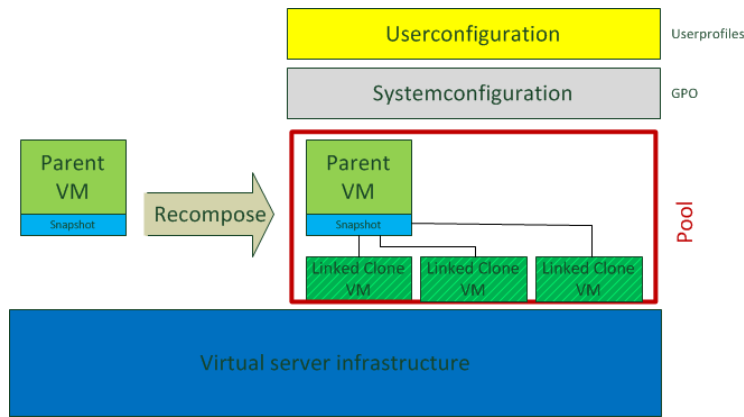


Image 3: Configuration of our setup

Image 3 shows the different layers of the setup. We had the underlying infrastructure running and created a Parent VM, which is the basis for every other VM. This parent is a clean Windows 7 with all updates and all drivers, but with no additional software. The Parent VM in the Pool is created for every different exam setup: there is one for Matlab exams, one for R-Studio exams, and so on.

Before the start of an exam, we check these images, bring them up to date and make small changes according to the exact setup required. After testing we deploy this image to the needed number of machines (called linked clones), and are ready for the exam. The system and user configuration are independent from the images; they can be changed at any time before the exam and are used after the next restart.

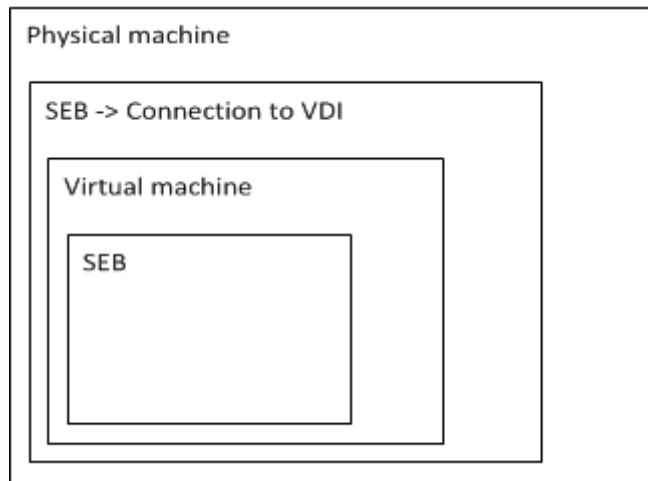


Image 4: Structure of VDI examinations

Image 4 shows the layers during an exam. Students log in on the physical machines (sometimes we use our exam accounts) and start the kiosk mode of SEB, which itself starts the VDI connector to the virtual machines. This VDI connector logs in using the same account as the physical machine, where a regular SEB can be started.

2.2.1. A WORKING VIRTUAL DESKTOP INFRASTRUCTURE

A fully 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 expertise 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 View, Citrix XenDesktop and Microsoft VDI.

Before implementing the exam setup you should perform a clean Windows 7 installation, which will be used as a master image.

- We have a VDI environment running.
- We have a master image with a clean Windows 7 installation (updates and drivers are 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; don't try to work with anything slower.

- We have a solid and working network.
- We have talked to the network administration about the capabilities of our network.

2.2.3. ENOUGH PHYSICAL MACHINES

One virtual machine needs one physical machine. We have about five percent spare machines (physical and virtual).

- We have checked our infrastructure and have enough working physical machines.

2.2.4. EVERYTHING ELSE

For different VDI setups you need different applications, licenses and configurations which may not be described in this document.

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

- We know exactly what sort of exam we want to provide.
- We know exactly what we do need and what we do not want.

3. TECHNICAL DOCUMENTATION

3.1. SETUP

Type	What we currently use
Physical servers	4x IBM x3750 M4 with Intel Xeon CPU E5-4640 with 786 GB Memory each.
Operating system (servers)	VMWare ESXi 6.0
Operating system (physical clients)	Windows 7 Enterprise x64
Operating system (virtual clients)	Windows 7 Enterprise x32
Connection software	VMWare View 7.1.0
Session-recording software	ObserveIT Enterprise 5.6 running on Microsoft Windows Server 2008 R2 with SQL-Server 2008 R2.

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 nearly 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 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 don't 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 can't 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/>

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

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

⁶http://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. We have to disallow such functions in every installed application if we 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. But, 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 absolutely 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, 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're 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 170 virtual machines. We tested the I/O performance by running a sequential and random read/write test on 170 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.

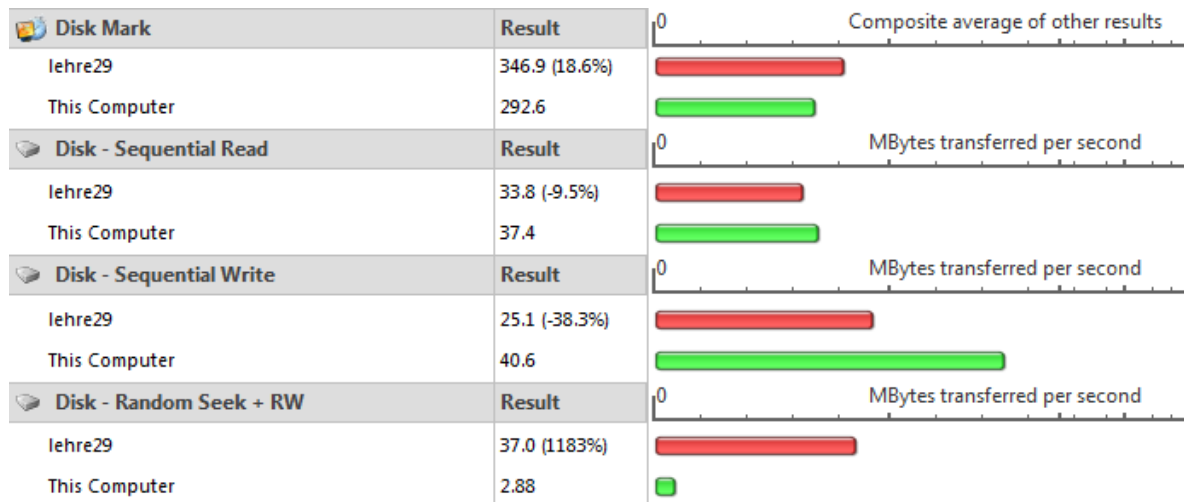


Image 5: Disk benchmark. The red bar is the virtual machine; the green bar is the physical machine.

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 2010.
- 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 several 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 edited files were then uploaded into the Moodle exam.

The virtual desktop features an installation of SEB 2.1.5, Matlab R2015a and a folder with the exam files.



Image 6: The icons on our virtual desktops

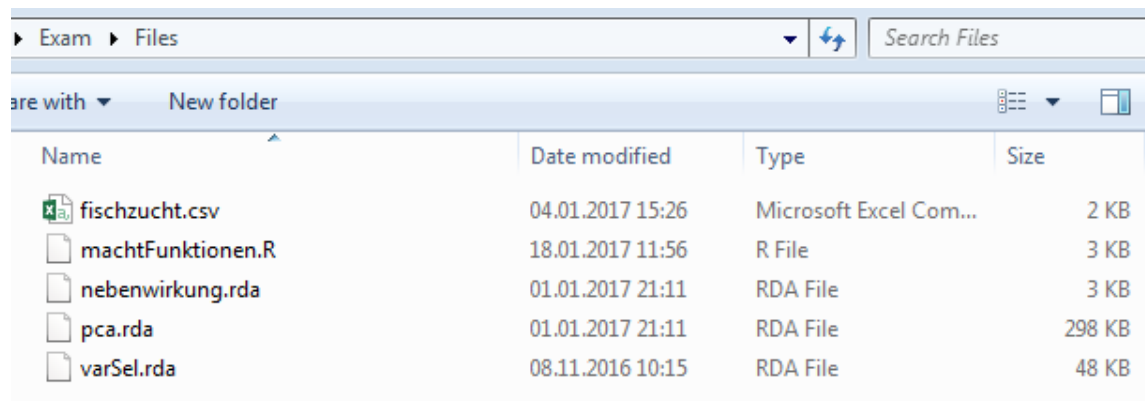


Image 7: Example of a list of files for an exam

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.

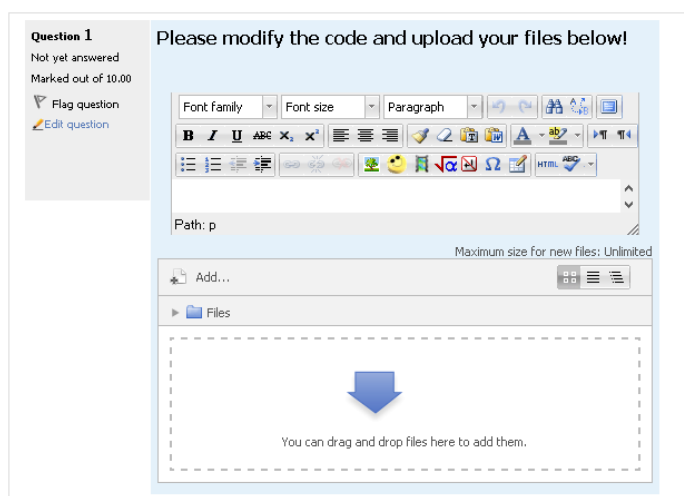


Image 8: Upload of files into our LMS

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

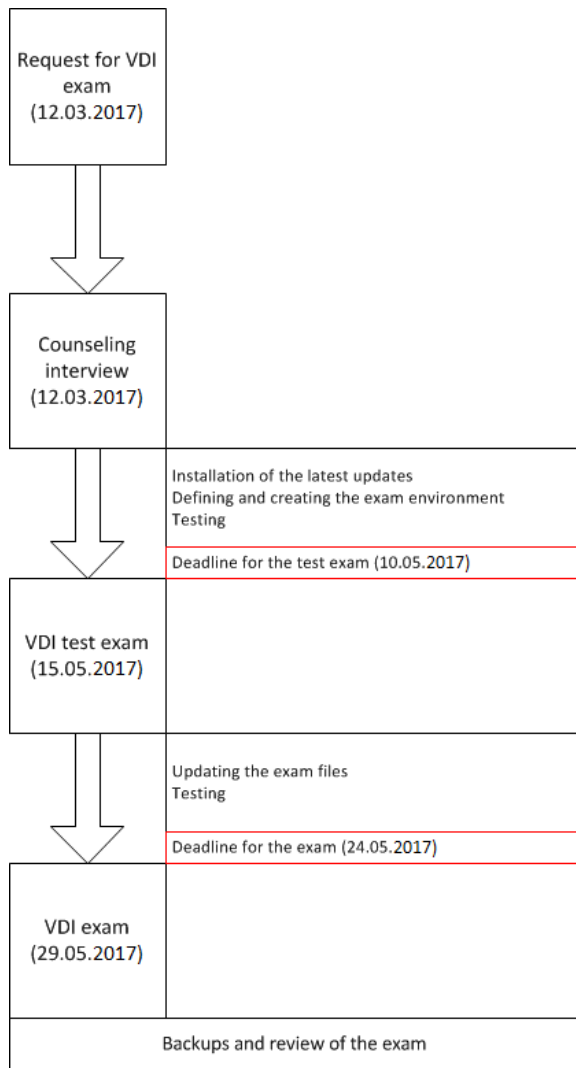


Image 9: VDI exam process

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 happens 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. SEB CONFIGURATION FILE

Please read the marked text in red carefully; this is how we managed to start the VDI connector in SEB. Normally SEB automatically starts a browser component and connects to an LMS. But With this configuration, it only starts the VDI connector application in kiosk mode.

Seb.ini for SEB 2.1.5 (Physical Machine):

```
[SEB]
[SebStarterConfigFile]
WriteSebStarterLogFile=0

[InsideSeb]

InsideSebEnableSwitchUser=0
InsideSebEnableLockThisComputer=0
InsideSebEnableChangeAPassword=0
InsideSebEnableStartTaskManager=0
InsideSebEnableLogOff=0
InsideSebEnableShutDown=0
InsideSebEnableEaseOfAccess=0
InsideSebEnableVmWareClientShade=0

[OutsideSeb]

OutsideSebEnableSwitchUser=1
OutsideSebEnableLockThisComputer=1
OutsideSebEnableChangeAPassword=1
OutsideSebEnableStartTaskManager=1
OutsideSebEnableLogOff=1
OutsideSebEnableShutDown=1
OutsideSebEnableEaseOfAccess=1
OutsideSebEnableVmWareClientShade=1

[SecurityOptions]

AllowVirtualMachine=0
ForceWindowsService=
lCreateNewDesktop=1
ShowSebApplicationChooser=1
HookMessages=1
EditRegistry=1
MonitorProcesses=0
ShutdownAfterAutostartProcessTerminates=0

[OnlineExam]

SebBrowser=VMware,C:\Program Files\VMware\VMware Horizon View Client\vmware-view.exe -
desktopProtocol PCOIP -desktopLayout fullscreen -serverURL view.ethz.ch -logInAsCurrentUser
true -desktopName "let-vdi-1-exam";

AutostartProcess=VMware

ExamUrl=http://www.safeexambrowser.org/

PermittedApplications=VMware,C:\Program Files\VMware\VMware Horizon View Client\vmware-
view.exe - desktopProtocol PCOIP -desktopLayout fullscreen -serverURL view.ethz.ch -
desktopName " let-vdi-1-exam";

[OtherOptions]

Win9xKillExplorer=1
Win9xScreenSaverRunning=0
StrongKillProcessesBefore=
StrongKillProcessesAfter=
```

5.2. GPOS

Policy	Setting
Always wait for the network at computer startup and logon	Enabled
Don't display the Getting Started welcome screen at logon	Enabled
Hide entry points for Fast User Switching	Enabled
Run logon scripts synchronously	Enabled
Turn off System Restore	Enabled
Turn off Autoplay (all devices)	Enabled
Turn off desktop gadgets	Enabled
Do not allow clipboard redirection	Enabled
Do not allow COM port redirection	Enabled
Do not allow drive redirection	Enabled
Do not allow LPT port redirection	Enabled
Do not allow smart card device Redirection	Enabled
Do not allow supported Plug and Play device redirection	Enabled
Remove "Disconnect" option from Shut Down dialog	Enabled
Remove Windows Security item from Start menu	Enabled
Disable Windows Error Reporting ⁷	Enabled
Configure Automatic Updates	Disabled
Prohibit access to the Control Panel ⁸	Enabled
Hide Change or Remove Programs page	Enabled
Remove Add or Remove Programs	Enabled
Enable screen saver	Disabled
Don't save settings at exit	Enabled
Hide Network Locations icon on Desktop	Enabled
Prevent adding, dragging, dropping and closing the Taskbar's toolbars	Enabled
Prohibit adjusting desktop toolbars	Enabled
Prohibit User from manually redirecting Profile Folders	Enabled
Remove Properties from the Computer icon context menu	Enabled
Remove Properties from the Documents icon context menu	Enabled
Remove Properties from the Recycle Bin context menu	Enabled
Remove the Desktop Cleanup Wizard	Enabled
Desktop Wallpaper	Disabled
Disable Active Desktop	Enabled
Microsoft Office Online ⁹	Disabled
Download Office Controls ¹⁰	Disabled
Prevent use of Offline Files folder	Enabled
Prohibit user configuration of Offline Files	Enabled
Add Search Internet link to Start Menu	Disabled
Add the Run command to the Start Menu	Disabled

⁷ Set this option only if everything works during testing.

⁸ This really prohibits access; disable it after exam creation and enable it after the exam.

⁹ Depends on MS Office version

¹⁰ Depends on MS Office version

Clear history of recently opened documents on exit	Enabled
Hide the notification area	Enabled
Lock all taskbar settings	Enabled
Remove access to the context menus for the taskbar	Enabled
Always wait for the network at computer startup and logon	Enabled
Remove All Programs list from the Start menu	Enabled
Remove and prevent access to the Shut Down, Restart, Sleep, and Hibernate commands	Enabled
Remove Balloon Tips on Start Menu Items	Enabled
Remove Default Programs link from the Start menu.	Enabled
Remove Downloads link from Start Menu	Enabled
Remove Favorites menu from Start Menu	Enabled
Remove frequent programs list from the Start Menu	Enabled
Remove Games link from Start Menu	Enabled
Remove Help menu from Start Menu	Enabled
Remove Homegroup link from Start Menu	Enabled
Remove links and access to Windows Update	Enabled
Remove Music icon from Start Menu	Enabled
Remove Network Connections from Start Menu	Enabled
Remove Network icon from Start Menu	Enabled
Remove Pictures icon from Start Menu	Enabled
Remove pinned programs from the Taskbar	Enabled
Remove pinned programs list from the Start Menu	Enabled
Remove programs on Settings menu	Enabled
Remove Recorded TV link from Start Menu	Enabled
Remove Run menu from Start Menu	Enabled
Remove Search link from Start Menu	Enabled
Remove the Action Center icon	Enabled
Remove the networking icon	Enabled
Remove user's folders from the Start Menu	Enabled
Remove Videos link from Start Menu	Enabled
Turn off all balloon notifications	Enabled
Don't display the Getting Started welcome screen at logon	Enabled
Prevent access to registry editing tools	Enabled
Prevent access to the command Prompt	Enabled
Windows Automatic Updates	Disabled
Remove Change Password	Enabled
Remove Lock Computer	Enabled
Remove Task Manager	Enabled
Remove access to use all Windows Update features	Enabled
Remove All Programs list from the Start menu	Enabled
Remove and prevent access to the Shut Down, Restart, Sleep, and Hibernate commands	Enabled
Remove Balloon Tips on Start Menu Items	Enabled
Remove Default Programs link from the Start menu.	Enabled
Remove Downloads link from Start Menu	Enabled

This list is as complete as possible, but there are thousands of other GPOs; You should go through all of them carefully and decide for yourself which are necessary for your purposes and which are not.

5.3. CHECKLISTS

5.3.1. 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 2016, 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

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.

5.3.2. 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

5.3.3. AFTER THE EXAM

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