# מושב 2.1 - תכן קונספטואלי וגיבוש חלופה נבחרת

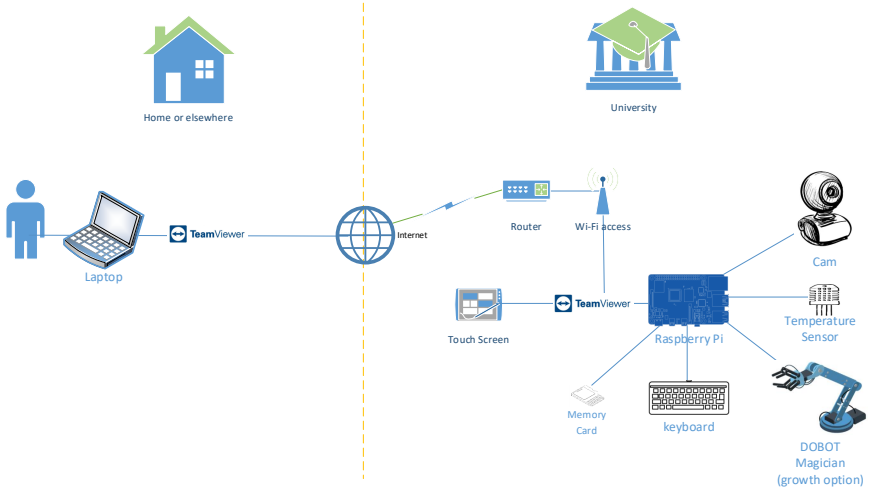
# Remote Laboratory for On Line Learning and Research

ד"ר מיכאל וינוקור
מכון טכנולוגי חולון - HIT

מכון טכנולוגי חולון
Holon Institute of Technology
50 YEARS OF EXCELLENCE

# Agenda

- Background
- Needs and stakeholders requirements
- System Scenarios, Model, Requirements and Eng. Characteristics
- Conceptual Design and Design Space Exploration
- Solution Selection and Robustness
- Verification and Validation
- Conclusions and Directions for Further Work



# The Story Behind the Presentation

A Practical Case of Conceptual Design:

- Design Space Exploration and Concept Selection
- Use of  Prototypes and Experiments Instead of Detailed Design
- Parallel Implementation in two Engineering Faculties:
  - HIT – Israel
  - UNSAM – Buenos Aires, Argentina

# Vision


*“to Create the ability to perform a laboratory experiment, anytime, anywhere”*

# Design Process References


- G. Pahl, W. Beitz, J. Feldhusen, and K. H. Grote, Engineering design: a systematic approach, 3rd ed. London, United Kindom: Springer, 2007 (1st ed. 1988)
- The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer
  by Jeffrey Liker | Jan 7, 2004
- Boehm, B (May 1988). "A Spiral Model of Software Development and Enhancement" .IEEE Computer 21 (5): 61–72.

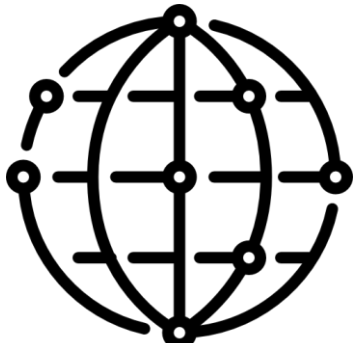
# The Design Process in a Nut Shell

## Similar Systems

VirtualLabs

Most similar systems are based on simulators rather than real lab operation

## Network



- Wi-Fi
- LoRa

(Comparison)

## Lab Equipment

- Controller
- Actuator

## Methods

- Ranking and Prioritizing Needs
  - NGT
  - BST
- Concept Selection
  - PM
  - AHP

# Acknowledgement

**Thanks to Shay and Adir for the prototype developed as part of their final research project for the M.Sc in Technology Management- Systems Engineering at HIT**

## Shay Safadel

- System Engineer of Electronic warfare suite for aircraft (Elbit Systems, Elisra, international business line)
- Bachelor's degree in Electrical and Electronics Engineering, HIT

## Adir Barel

- Production Development Engineer (NPI) for Radar Communication and Advanced RF Systems (Elbit Systems)
- Bachelor's degree in Electrical and Electronics Engineering, HIT

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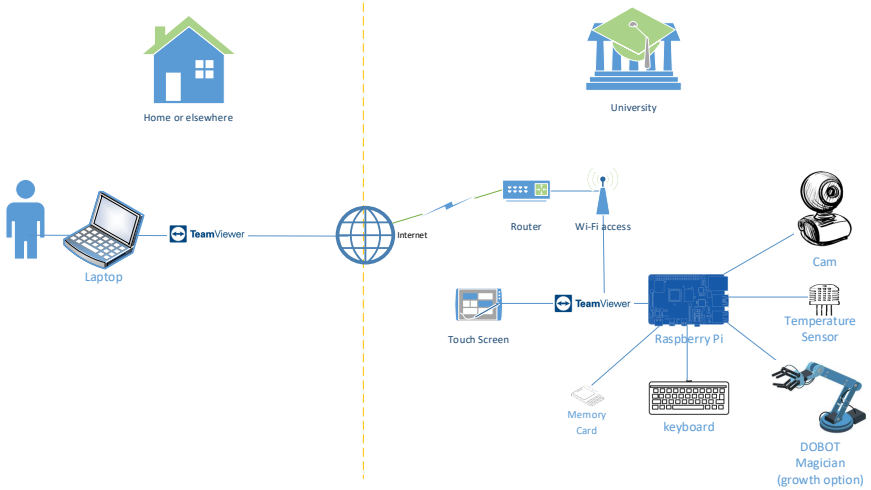


# Stakeholder Needs

Some of the needs:

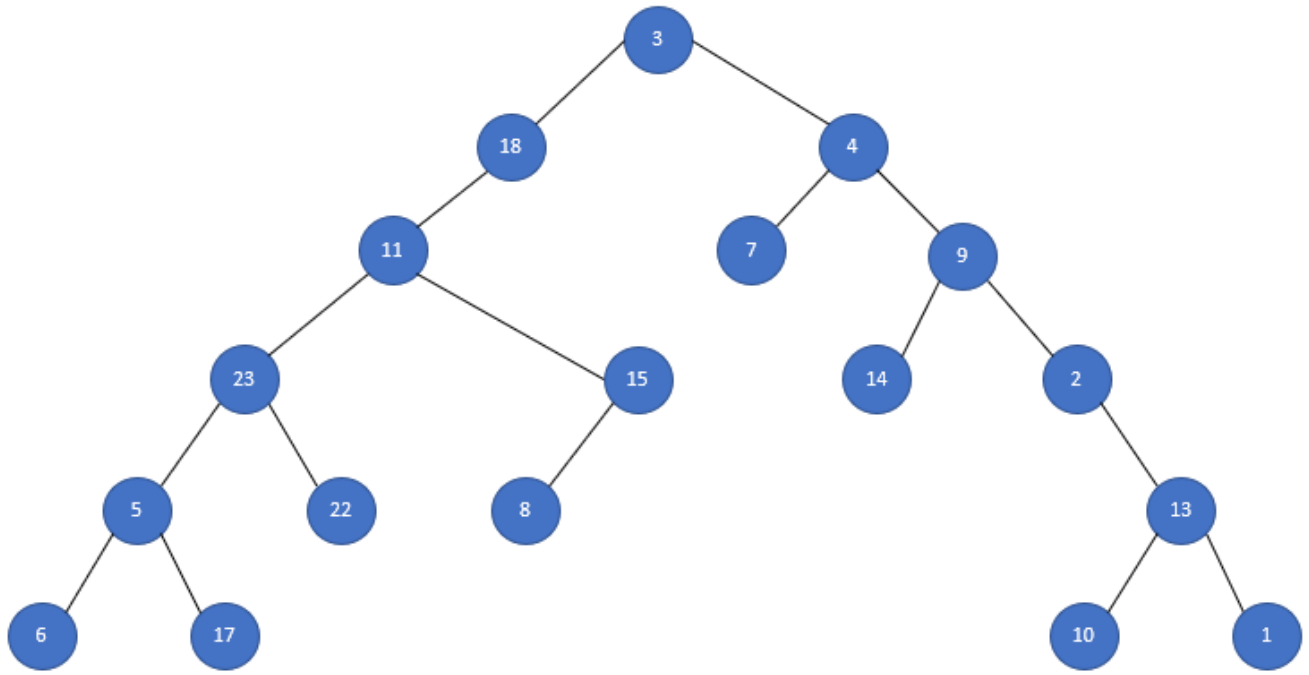
- Remote connection to the controller interface in the laboratory at the institute
- Control a camera using the controller
- Ability for a lecturer to teach students through remote operation that he himself performs
- Length of takeover session of at least 3 hours
- Hybrid learning (laboratory for remote operation and also for frontal operation)

# Needs Prioritization

## NGT

| I.D | The Need | Participants | | | | | Average | Priority Rank |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | | |
| **4.3.1** | Remote connection to the controller interface in the laboratory at the institute | 12 | 10 | 10 | 15 | 13 | 12 | **1** |
| **4.3.10** | Availability for remote operation anytime | 9 | 8 | 7 | 8 | 10 | 8.4 | **2** |
| **4.3.13** | High reliability for remote connection (without interruptions) | 7 | 10 | 10 | 7 | 8 | 8.4 | **2** |
| **4.3.2** | Writing code in the controller by remote operation | 8 | 8 | 8 | 10 | 7 | 8.2 | **4** |

## BST – Sensitivity Test



# Stakeholder Requirements

| ID | Stackholder Need | Req ID | Stakeholder Requirement |
|---|---|---|---|
| 4.3.1 | Remote connection to the controller interface in the laboratory at the institute | CR-1 | The system shall contain a controller which is located in the IoT lab at the academic institution. |
| | | CR-2 | The system shall contain an HMI or software which allow the user to connect in remote control to the controller in the lab. |
| 4.3.10 | Availability for remote operation anytime | CR-3 | The system shall be available for free use of remote operation by students 24/7 (except during classes, class preparation by lecturer and maintenance activity). |
| | | CR-4 | The system shall be available for use by lecturer and student during class time. |
| 4.3.13 | High reliability for remote connection (without interruptions) | CR-5 | The system shall have at least 98% of reliability during class time. |
| | | CR-6 | The system shall have at least 70% of reliability for free use by students. |
| 4.3.2 | Writing code in the controller by remote operation | CR-7 | The system shall allow the user to write code in the Terminal window of the controller by remote control. |
| | | CR-8 | The system shall allow the user to write code in Python language in a built-in software on the controller by remote control. |

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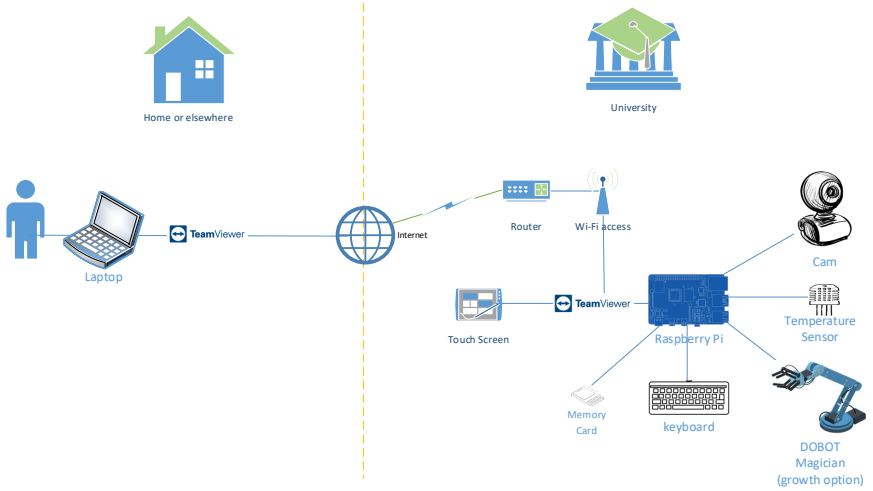
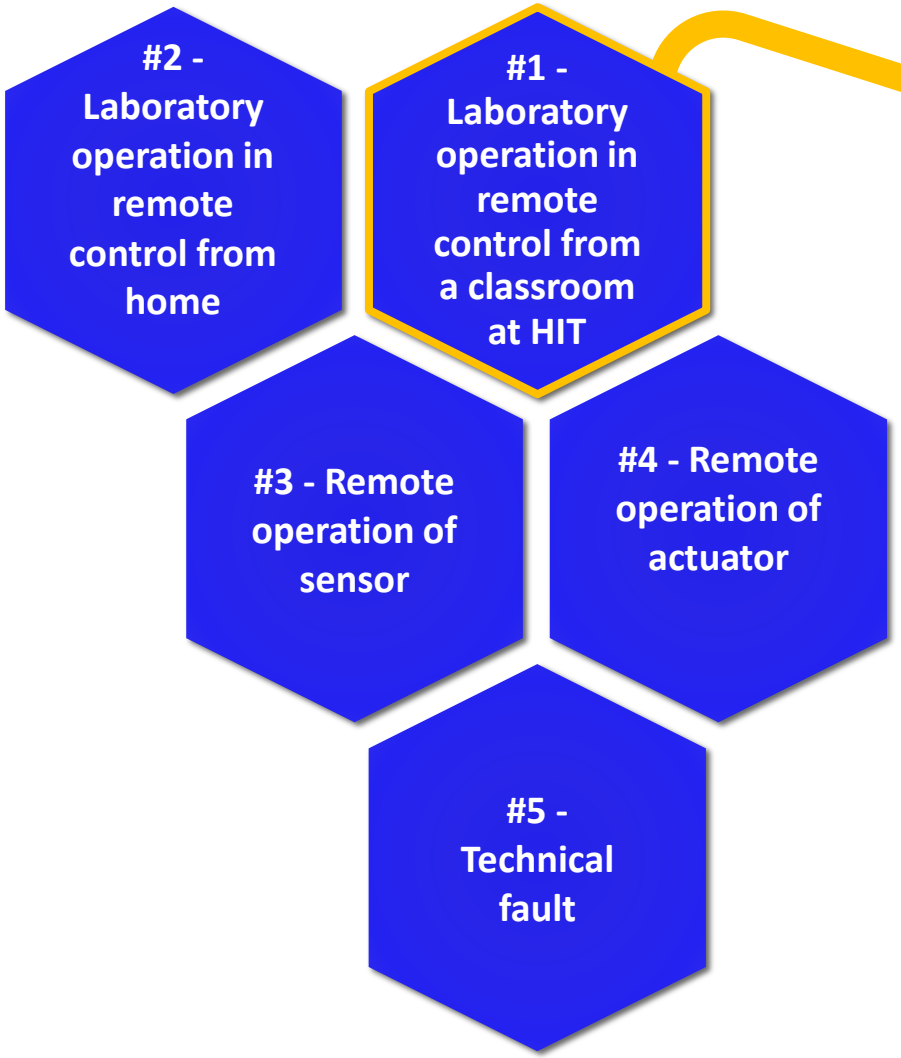
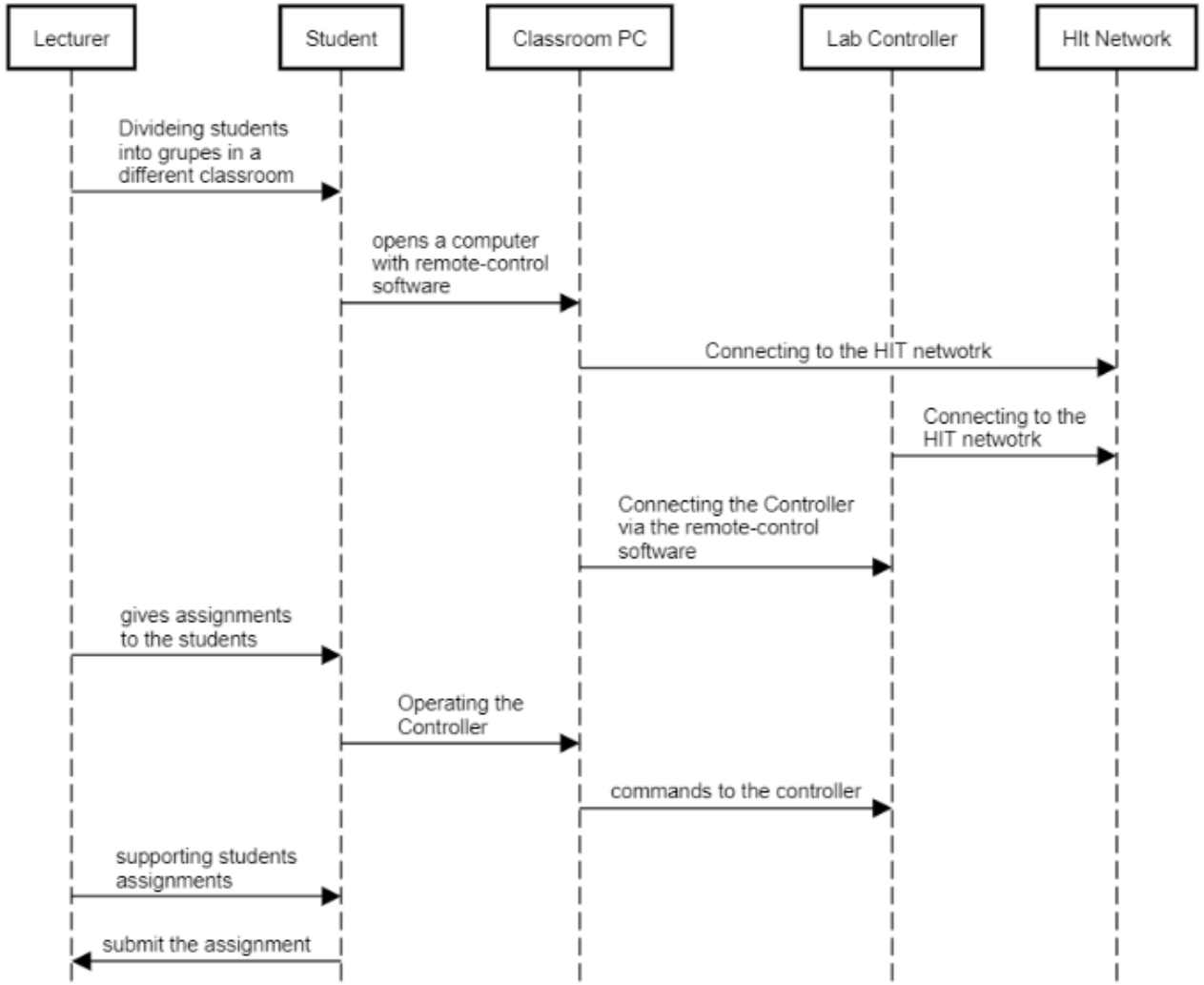
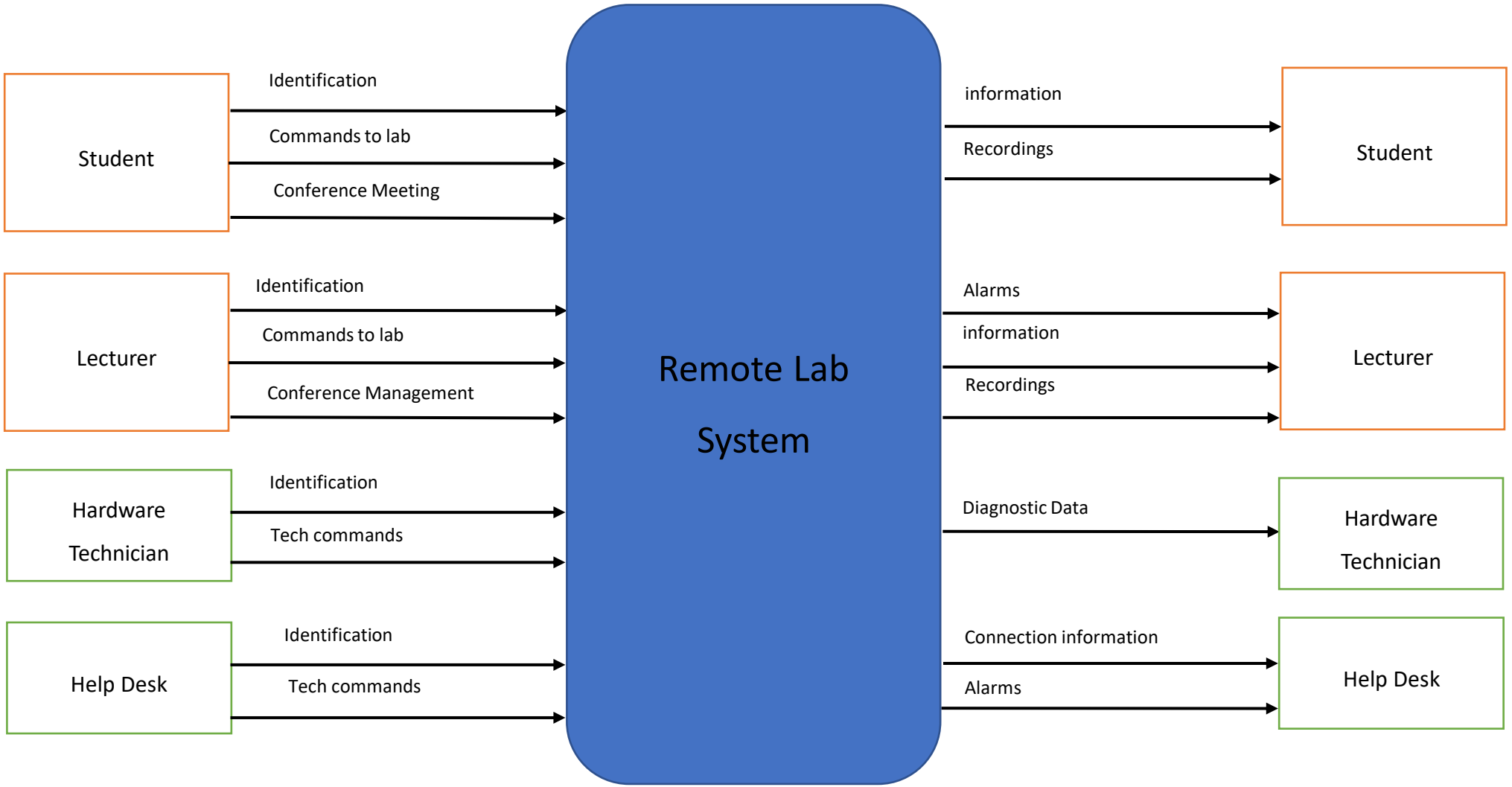


# System Scenarios

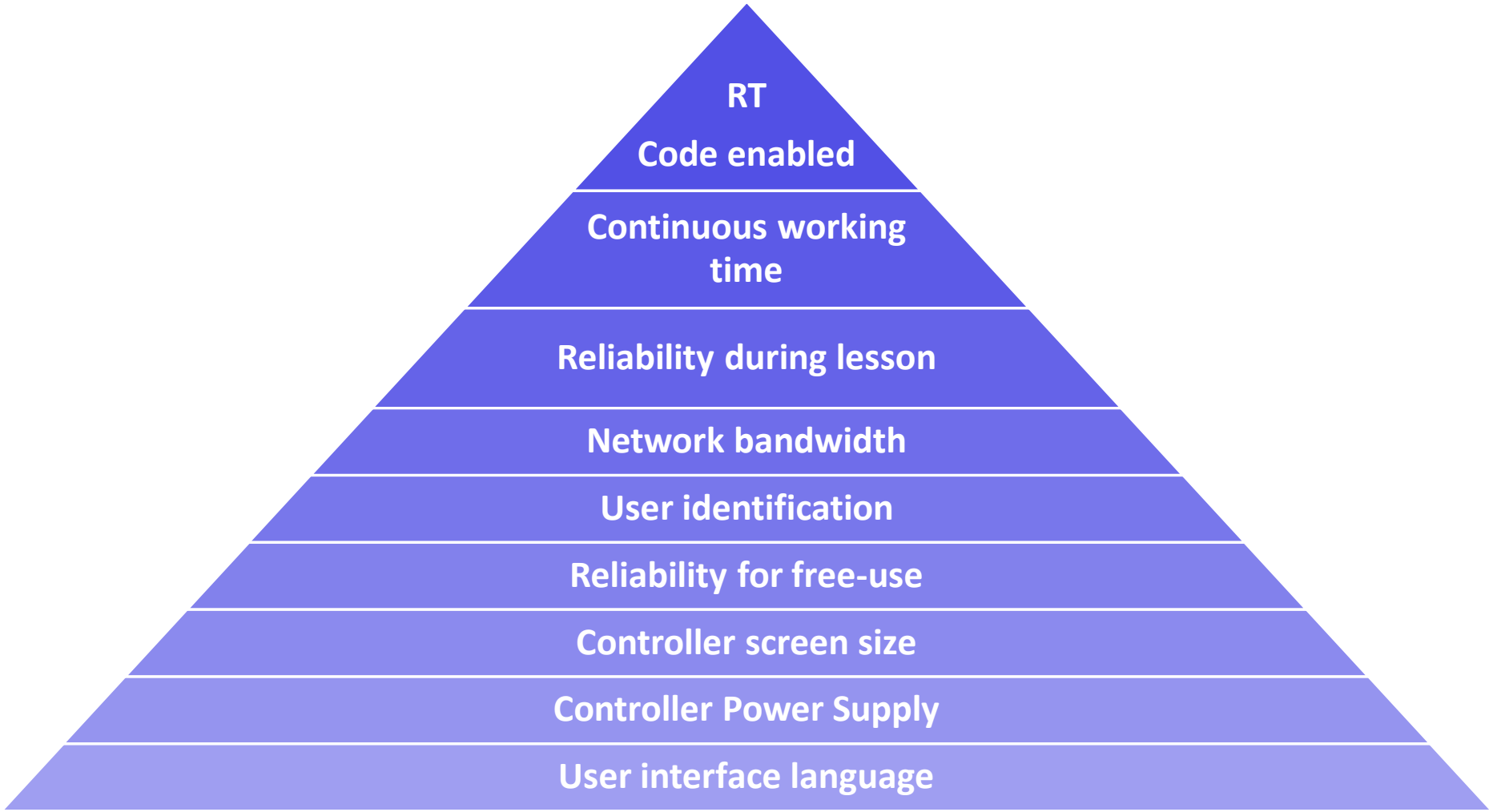


# System Model



# Engineering Characteristics



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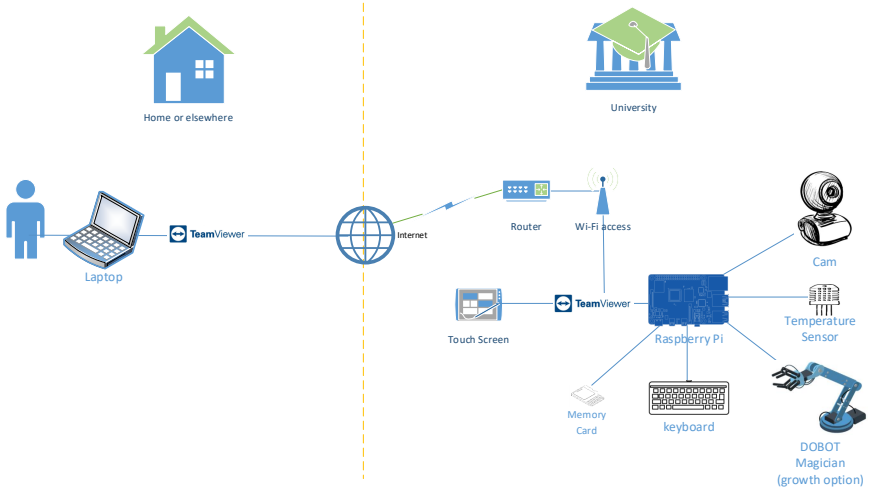

# Concepts

Performing laboratory exercises on a personal computer at the student's home with lab simulation, submitting the solution to the lecturer. The lecturer checks the submission on laboratory equipment in an online conversation with each student.

Performing laboratory exercises on a personal computer at the student's home in an online connection to laboratory equipment.

Each student will have laboratory equipment at home to perform the experiment and submits the results of the experiment to the lecturer.

The lab will be displayed in the student home as a hologram and the student will operate it using a smart device.

Each student will have 3D glasses that will show him the lab in 3D. The student will operate the lab using voice and hand commands.

# Solution Alternatives (G. Pahl et al.)

| Concepts / Design problems | Concept 1- One for all | Concept 2- One on one | Concept 3- Home KIT | Concept 4- Hologram | Concept 5- 3D |
|---|---|---|---|---|---|
| **Connection to Lab Equipment** | USB | LORA | USB | WIFI | LAN Cable |
| **Displaying Information to User (Student/Researcher)** | PC | LAPTOP | Raspberry PI | Projector on Screen | VR Glasses |
| **Displaying Information to Instructor** | Touch Screen | LAPTOP | LAPTOP | LAPTOP | 3D glasses |
| **Controlling the Lab Equipment** | Raspberry PI | Nvidia jetson | Arduino | Raspberry PI | SBC |
| **Control of exercise by User** | PC U. I | LAPTOP U. I | External keyboard | Smart Phone | Virtual keyboard |
| **Management of student exercise** | Simulator + ZOOM application | TeamViewer | ZOOM application | SKYPE application | VR Glasses |
| **Remote Control on the Controller Software** | N.A. | TeamViewer | Remote Desktop | AnyDesk | Virtual management application |
| **Data Collection and Recordings** | Zoom Server | Academic institute Server | Memory Card | Cloud | Cloud |

# Solution Alternatives – More Concepts (The Toyota Way)

| Concepts / Design problems | Concept 6- One for all from Home | Concept 7- One on One, as simple as that |
|---|---|---|
| **Connection to Lab Equipment** | LAN cable | WIFI |
| **Displaying Information to User (Student/Researcher)** | LAPTOP | LAPTOP |
| **Displaying Information to Instructor** | LAPTOP | LAPTOP |
| **Controlling the Lab Equipment** | Raspberry PI | Raspberry PI |
| **Control of exercise by User** | LAPTOP U. I | LAPTOP U. I |
| **Management of student exercise** | N.A. | ZOOM application |
| **Remote Control on the Controller Software** | TeamViewer | TeamViewer |
| **Data Collection and Recordings** | Academic institute Server | Memory Card |

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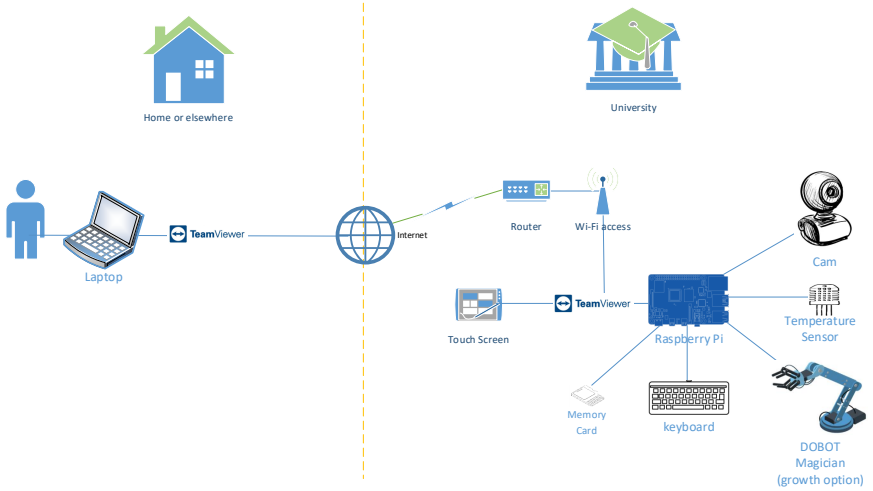


# Solution Choice - Screening

| Concepts / Engineering characteristic | Concept 1- One for all | Concept 2- One on one | Concept 3- Home KIT | Concept 4- Hologram | Concept 5- 3D | Concept 6- One for all from Home | Concept 7- One on One, as simple as that |
|---|---|---|---|---|---|---|---|
| Code Writing | 0 | 0 | 0 | 0 | 0 | - | 0 |
| Continuous working time | - | 0 | + | - | - | - - | 0 |
| Reliability during lesson | 0 | 0 | + | - | - | 0 | + |
| Network bandwidth | + | 0 | + | - | + + | 0 | + |
| User identification | - | 0 | 0 | 0 | 0 | - | + |
| Total "+" | 1 | 0 | 3 | 0 | 2 | 0 | 3 |
| Total "-" | 2 | 0 | 0 | 3 | 3 | 4 | 0 |
| Summarized importance | -1 | 0 | 3 | -3 | -3 | -4 | 3 |
| Alternative rating | 4 | 3 | 1 | 5 | 5 | 7 | 1 |

# Solution Choice - Scoring

| Concepts / Engineering characteristic | Characteristic Weight (%) | Concept 2- One on one | | Concept 3- Home KIT | | Concept 7- One on One, as simple as that | |
|---|---|---|---|---|---|---|---|
| | | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| Code Writing | 27.6 | 3 | 0.828 | 4 | 1.104 | 3 | 0.828 |
| Continuous working time | 16.5 | 3 | 0.495 | 5 | 0.825 | 3 | 0.495 |
| Reliability during lesson | 13.2 | 3 | 0.396 | 4 | 0.528 | 4 | 0.528 |
| Network bandwidth | 10.3 | 3 | 0.309 | 4 | 0.412 | 4 | 0.412 |
| User identification | 9.5 | 3 | 0.285 | 3 | 0.285 | 4 | 0.38 |
| Reliability for free-use | 9.1 | 3 | 0.273 | 5 | 0.455 | 4 | 0.364 |
| Controller screen size | 4.9 | 3 | 0.147 | 3 | 0.147 | 3 | 0.147 |
| Controller Power Supply | 3.7 | 3 | 0.111 | 3 | 0.111 | 3 | 0.111 |
| Controller Power Freq | 3.7 | 3 | 0.111 | 3 | 0.111 | 3 | 0.111 |
| User interface language | 1.6 | 3 | 0.48 | 3 | 0.48 | 3 | 0.048 |
| Summarized importance | 100 | 3 | 3 | 3 | 4.02 | 3 | 3.42 |
| Alternative rating | | 3 | | 1 | | 2 | |

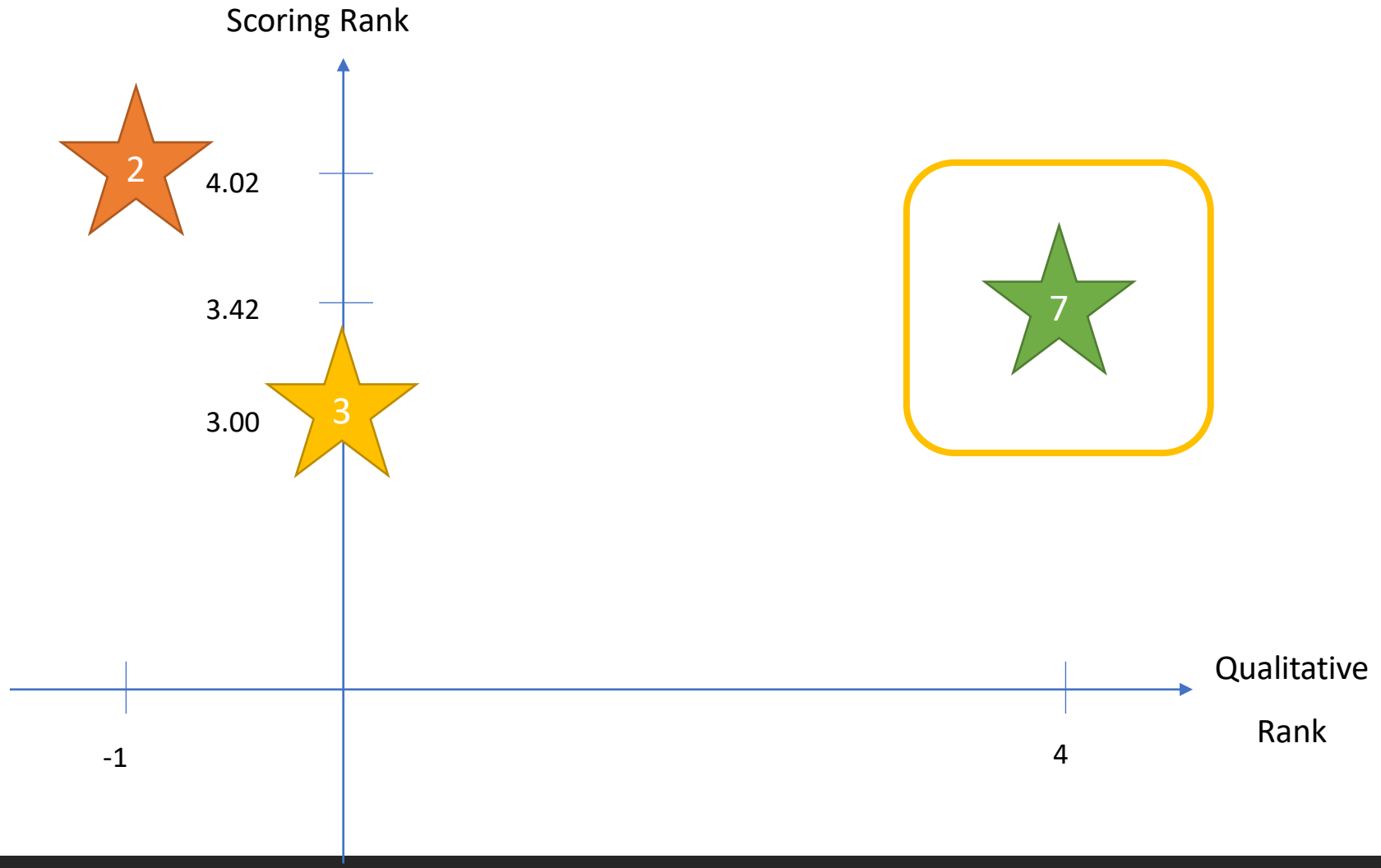
# Solution Choice - Qualitative Criteria

| Concepts / Qualitative Criteria | Concept 2- One on one | Concept 3- Home KIT | Concept 7- One on One, as simple as that |
|---|---|---|---|
| TTM | 0 | + | + |
| LCC | 0 | - | + |
| Development Team Experience | 0 | + | + |
| Maintainability | 0 | - - | + |
| Total "+" | 0 | 2 | 4 |
| Total "-" | 0 | 3 | 0 |
| Summarized importance | 0 | -1 | 4 |
| Alternative rating | 2 | 3 | 1 |

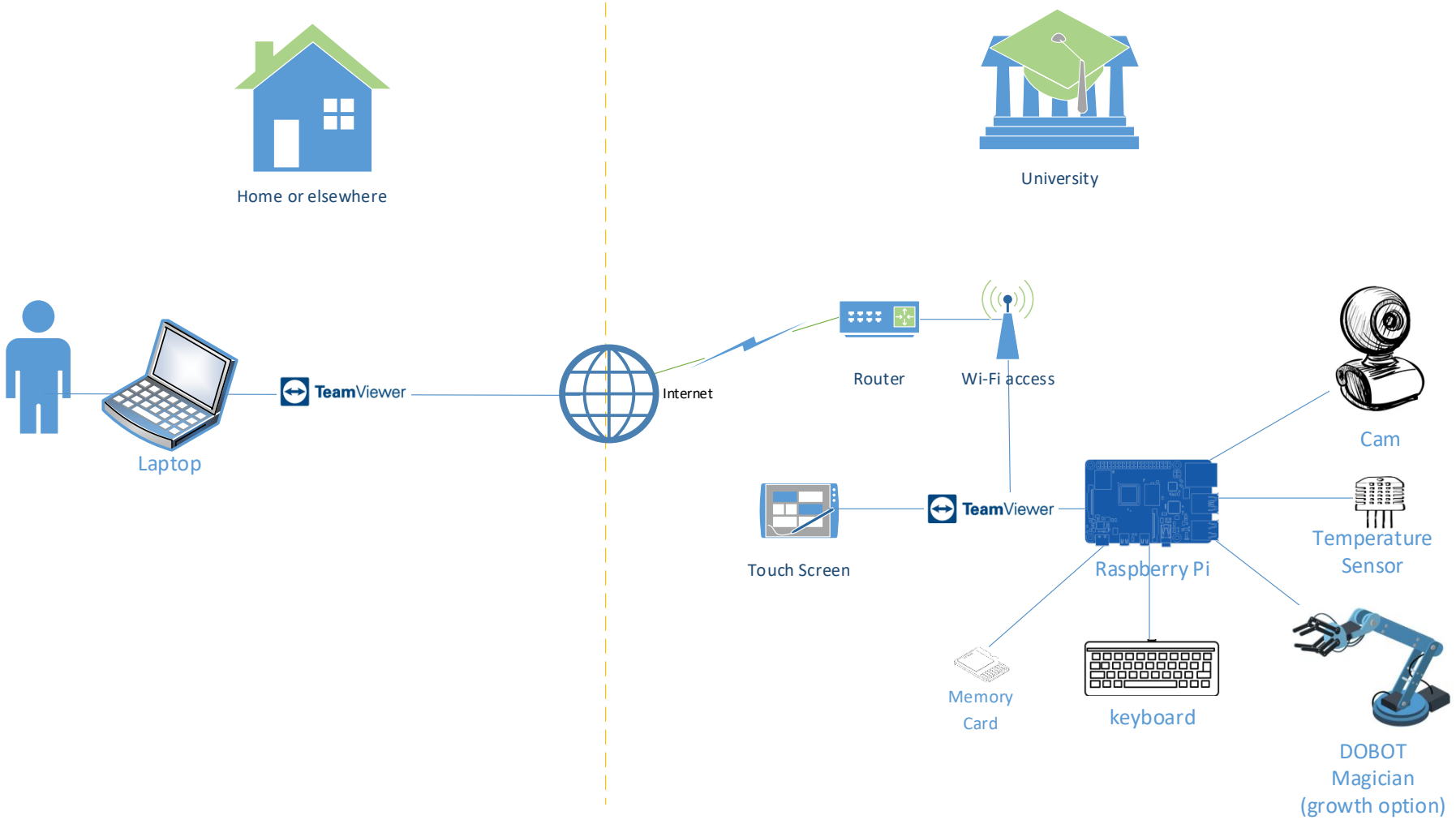
# Risk Analysis

| Topic | failure mode | failure prob. | failure Severity | Calculated Risk | Improvement | failure prob. | failure Severity | Calculated Risk |
|---|---|---|---|---|---|---|---|---|
| **Hardware Equipment** | The controller is faulty | 2 | 4 | 8 | Scheduling periodic maintenance | 1 | 4 | **4** |
| **Hardware Equipment** | The sensors are faulty | 2 | 2 | 4 | Connecting two sensors of each type | 1 | 2 | **2** |
| **Connection** | Failure to connect to remote lab | 3 | 5 | 15 | Allocation of Helpdesk manpower | 2 | 3 | **6** |
| **Connection** | Unstable connection due to bandwidth load causes slow operation | 3 | 4 | 12 | Design of a separate Internet connection for this lab (independent of an Internet connection from other areas of the college) | 1 | 4 | **4** |
| **Cyber** | Hackers remotely take over the lab equipment | 2 | 4 | 8 | Add encryption to the Internet connection in the lab | 1 | 4 | **4** |
| **Controller Display** | The screen does not work | 2 | 4 | 8 | Add an HDMI cable to an external monitor | 1 | 3 | **3** |
| **Reliability** | The actual reliability of the system will not meet the requirement | 4 | 5 | 20 | Spare kits available for use in remote operation in case of a kit failure | 1 | 5 | **5** |
| **Maintainability** | The manpower supporting the maintenance of the system will not be qualified | 3 | 3 | 9 | Defining a training program for technical support and periodic renewal of procedures. | 2 | 3 | **6** |

# Solution Choice - Two-dimensional Rating



# Selected Architecture (“One on One – as simple as that”)



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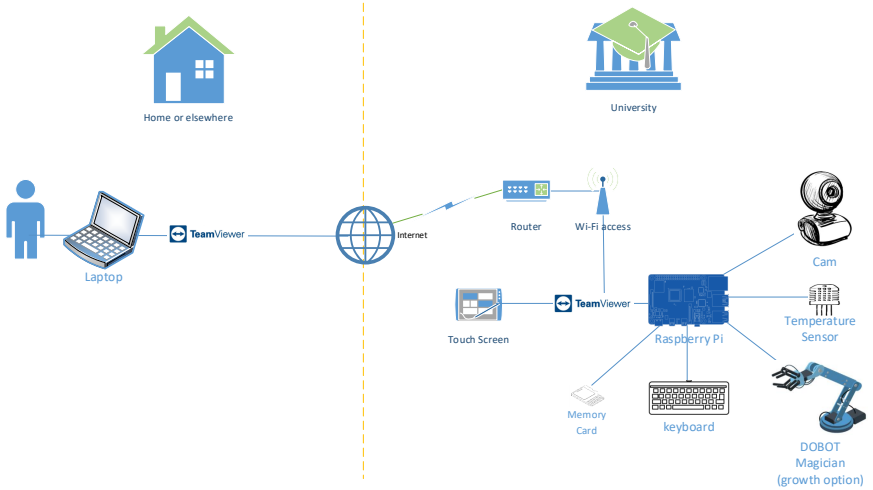
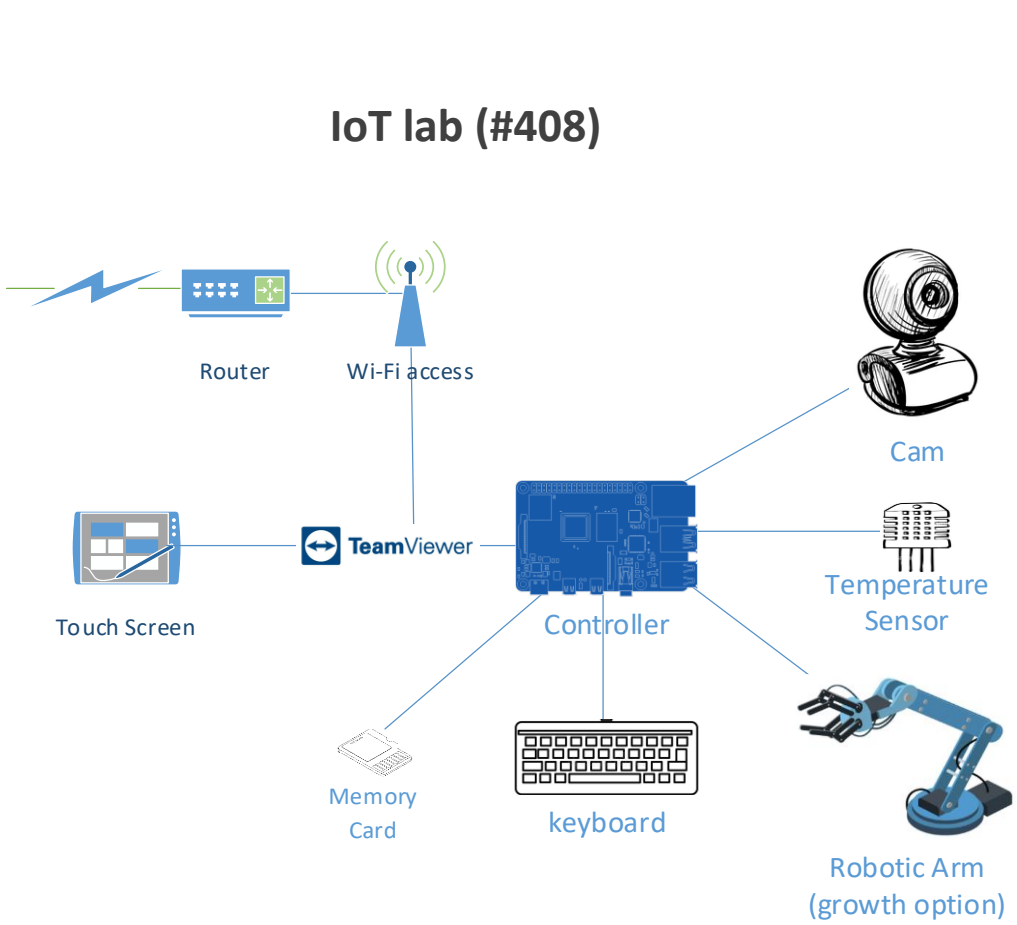
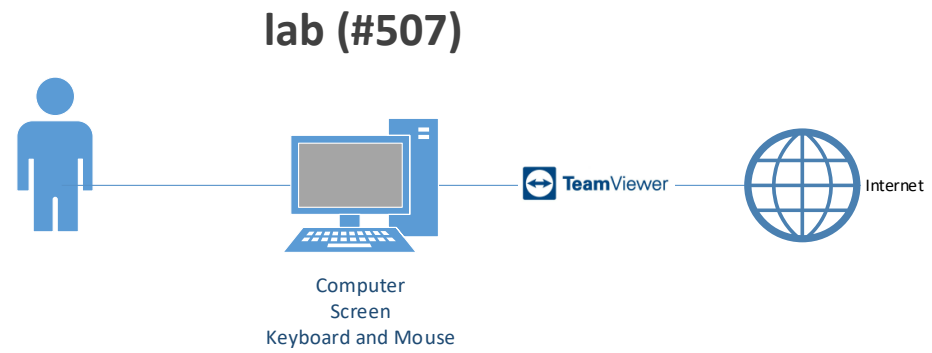


# Test Sites


IoT lab (#408)
Router
Wi-Fi access
Cam
Touch Screen
TeamViewer
Controller
Temperature Sensor
Memory Card
keyboard
Robotic Arm (growth option)


lab (#507)
TeamViewer
Internet
Computer
Screen
Keyboard and Mouse


Home
TeamViewer
Internet
Laptop

# Test Groups

| Test Group #id | Description | Test Site | System Requirements covered (SysRs-#) |
|---|---|---|---|
| TG-1 | Visual Inspection and basic controller operation | - IoT Lab #408 | 1, 2, 24, 25, 35 |
| TG-2 | Laboratory operation in remote control from a classroom | - IoT Lab #408, Lab #507 | 7, 8, 9, 10, 11, 31, 32 |
| TG-3 | Laboratory operation in remote control from home | - IoT Lab #408, Home | 7, 8, 9, 10, 11, 31, 32 |
| TG-4 | Remote operation of sensor | - IoT Lab #408, Lab #507 / Home | 12, 13, 16, 17, 18, 19, 20, 21, 22 |
| TG-5 | Remote operation of actuator | - IoT Lab #408 | 36, 37 |
| TG-6 | Reliability and Availability and Technical faults | - IoT Lab #408, Lab #507 | 3, 4, 5, 6, 11, 27 |
| TG-7 | Qualification Test | - IoT Lab #408 | 23, 38 |
| TG-8 | Lesson management | - IoT Lab #408 | 14, 15, 26, 27, 28, 29, 33, 34, 39 |

# Test Cases

**Test Cases for Group #1 - Visual Inspection and basic controller operation**

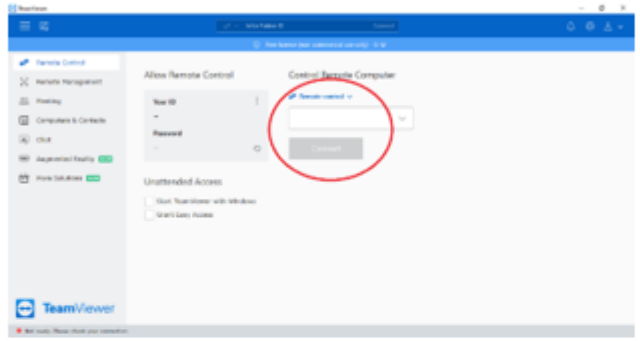
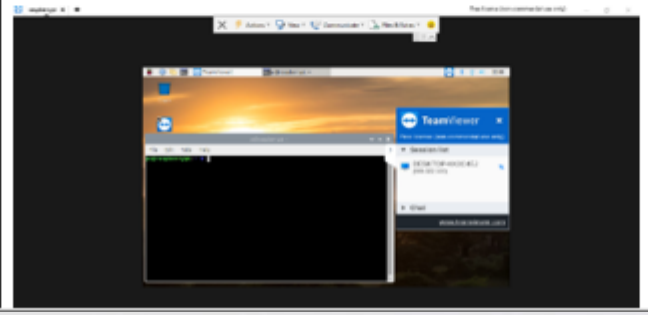
| Test Case #id | Description | Target | SysRs-# covered |
|---|---|---|---|
| TC-1 | Equipment setup and verification | Make sure all existing components are suitable for the laboratory infrastructure. | 1, 35 |
| TC-2 | Controller operational system | Install OS on the controller according 9.1.3. | 2 |
| TC-3 | Remote control software | Install TeamViewer on the controller according Appendix B. | 2 |
| TC-4 | Power Up | Verify system is running properly | 1 |
| TC-5 | Internet access | Ensure a stable internet connection | 24, 25 |

# Verification Matrix

| Req #ID | Req Description | TC #ID | TC Description |
|---|---|---|---|
| **SysRs-1** | The system shall contain a controller which is located in the IoT lab at the academic institution. | TC-1 | Equipment setup and verification |
| | | TC-4 | Power Up |
| **SysRs-2** | The system shall contain an HMI or software whice allow the user to connect in remote control to the controller in the lab. | TC-2 | Controller operational system |
| | | TC-3 | Remote control software |
| **SysRs-3** | The system shall be available for free use of remote operation by students 24/7 (except during classes, class preperation by lecturer and maintenance activity). | TC-20 | Access to connecting the Lab at different times during the day |

# Acceptance Tests HIT Prototype

- TC-1: Equipment setup
- TC-2: Controller operational system
- TC-5: Internet access
- TC-3: Remote control software Installation
  - Raspberry Pi installation
  - Computer tester installation
- TC-8: Connecting from different places
- TC-10: Camera control
- TC-11: Camera remote control
  - Camera control via Terminal
  - Camera control via Python
- TC-12: temperature sampling

| | | |
|---|---|---|
| The following steps will be performed in the remote side (lab #507, home or elsewhere). | | |
| 4. | Enter the ID of the Raspberry pi side in the following area:  | PASS (06/04/22) |
| 5. | Enter the password of the TeamViewer on the Raspberry PI. | PASS (06/04/22) |
| 6. | Verify remote connection successful:  | PASS (06/04/22) Note: Observed when connecting remotely that the screen of the controller is displayed in only a small size. This can be changed in |

# On Line Test from Israel and Argentina

TC-13: motion sampling

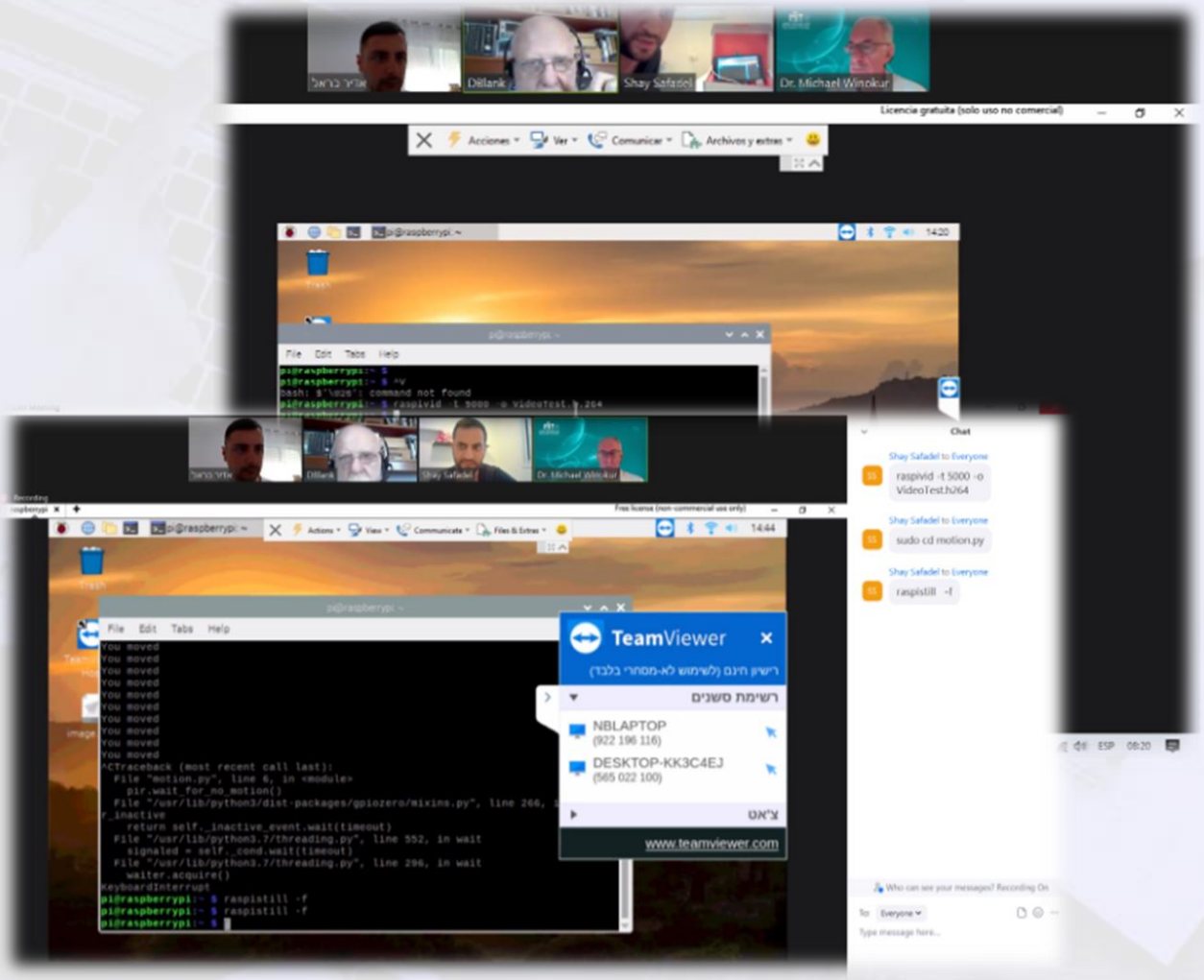
TC-8: Connecting from different places

- Full Screen connection
- Home and Aboard

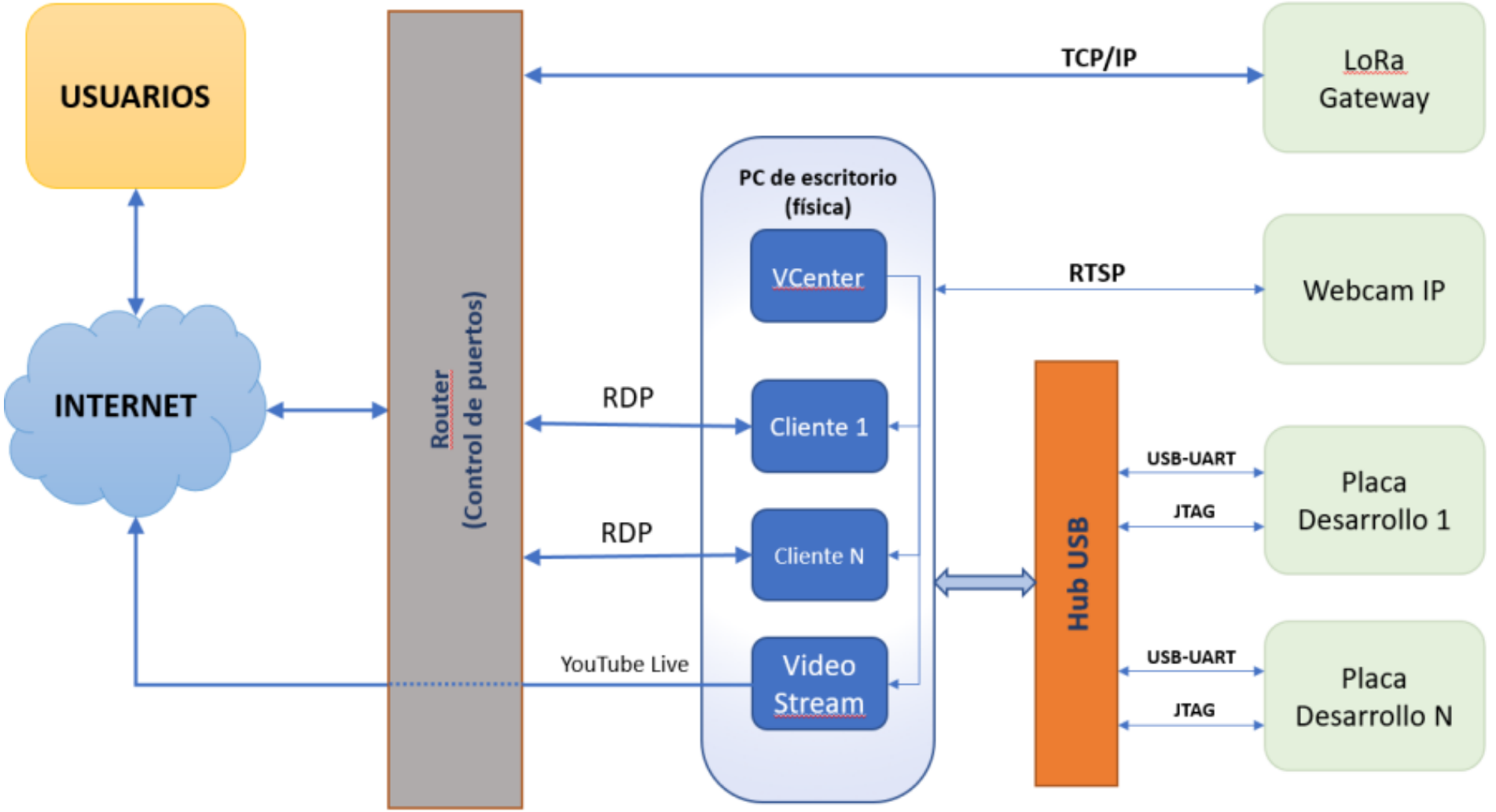
TC-11: Camera remote control –

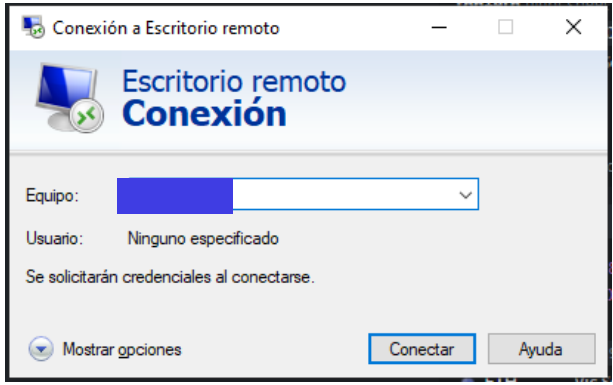
Camera control via Terminal

TC-13: motion sampling



# UNSAM prototype



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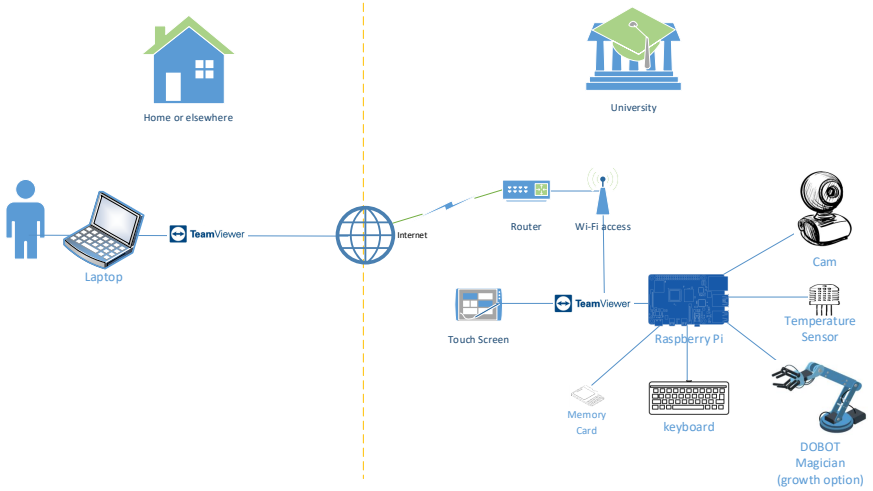

# Summary and Directions for Further Work

- Combined conceptual design and prototype implementation
- System prototypes are  ready for use
- Future steps (תשפ"ג)
  - Implementation in courses at UNSAM and HIT with students cross participation
  - Research on the effectiveness of use in ongoing M.Sc. projects at HIT
  - Use by researchers in the "IDEATION" EC project
  - Seminar on Digital Transformation in Higher Education, HIT end of Nov. 2022
  - Workshop on Remote Lab learning – UNSAM, Argentina 11-12 April 2023.


# Thank you

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