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Remote Laboratories Resource Management Learning System Using Game-Based Facilities

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ABSTRACT
In an educational setting, learners are anticipated to identify problems, create them possess hypothesis or inquire about question, collect prove or conduct self-directed investigations/experiments, analyze the evidence/data collected, reach conclusions, evaluate them possess advance and at long last reflect on their request handle, Virtual and remote labs have been around for almost twenty years and while they have been constantly gaining popularity since their appearance, there are still many people in the control education community who either do not know many details about them or do not know them at all, Physical laboratories show security, haptic, fabric and logistic imperatives that regularly require coordinated research facility methods that are hindering to students' development of knowledge, The research is aim at Remote controlled laboratory is based on the use of real instrumentations and components, in which experiments will be completely conducted and controlled remotely by the students through the internet. In this work, a novel laboratory learning system is proposing, which provides the flexibility of deployment on any physical infrastructure, integrability with other different physical laboratory resources, and scalability. Twenty-five (25) student were used to practical slots, Then, a matching game-based framework is proposing to optimally solve the formulating problem. Simulation results will show the significance of the proposing matching game-based framework compared to other students to resources association schemes, in minimizing the number of blocked time slots per acquiring student and maximizing the resources utilization efficiency.
Keywords: laboratories, remote, learning and resources

INTRODUCTION
Virtual and remote labs have been around for almost twenty years and while they have been constantly gaining popularity since their appearance, there are still many people in the control education community who either do not know many details about them or do not know them at all (Heradio et al., 2016). Physical laboratories show security, haptic, fabric and logistic imperatives that regularly require coordinated research facility methods that are hindering to students' development of knowledge. Due to these imperatives, physical research facilities don't continuously accomplish their craved learning results Technology-facilitated virtual research facilities have been accepting increasing consideration as a potential alternative to targeting some of the desired results of the college instructing research facilities (Nolen & Koretsky, 2018). This is to say that, there are existing spaces to be filled enough in having a better benefits of the facilities. So that, opportunities will be utilized accordingly. Remote laboratories provide opportunities and flexibilities for students to conduct experiments by the level of ability and pace of learning each student, anytime and anywhere (Gutiérrez, W., Fernandaz, M. & Mantilla, W. 2016): (Maiti, A.,Wuttke, H. & Zutin, D. 2018). Hence, remote laboratory systems have been designed to

perform the remote access platform for learners from faraway places (Taha & Hanbury, 2015): (Machado, G., Silva, Y. & De Lucena, V. 2019). In elucidating the benefits of physical laboratory requirements Mamani, Garcia-Penalvo, Conde & Goncelves (2021) as submitted by Thames & Wellman (2011) holds that, historically, physical laboratory requirements have limited the ability to support flexible usage and sharing of resources. However, the rapid development of computer technologies and networking have supported the transformation to remote laboratories. Remote laboratories are important tools for both student learning and scientific research. They do represent a significant investment that needs to be developed and maintained. However, there challenges in among other things the proper application of the laboratory learning systems. In view of this Felipe & Rivera (2016) holds that, one of the major challenges in laboratory learning systems is the lack of standardization. Which means that laboratory learning systems that runs and controls the remote laboratory may not be modular, portable, flexible, or scale. The most important feature of laboratory learning systems is to support sharing expensive resources across the world (Heradio, R., Luis de la Torre, Sebastian, D. 2018):(Lei, Z., Hong, Z., Wenshan, H., Qijun D., Dongguo Z., & Zhi-Wei Liu, 2017). In this regard, some benefits such as flexible access, sharing and integrating remote laboratories' resources, and modular architecture, have been shown to increase the attention of users (Zhongcheng, L., Hong,Z., Wenshan HU, Qijun D., Dongguo Z., Zhi-Wei L., & Jingang L., 2018): (Scapolla, M, Bagnasco, A., Parodi,G., Ponta, D.,2005). Regarding a flexible and integrable platform, resource allocations are considered a significant issue. Thus, proper scheduling can respond to the demand for having access to the remote laboratory. Therefore, this research study proposed a novel laboratory learning system that provides modularity of the software platform, flexibility of deployment on any physical infrastructure as well as integrality with other different physical infrastructures elsewhere as follows:

a) A novel laboratory learning system will be design which considers flexibility, integrality, modularity, and providing maximum utilization of the available physical resources.

b) A mathematical model for proposing laboratory learning system is will be formulating, such that it provides the relations between the students, experiments, software and hardware resources, physical and virtual machines, the available time slots for reservation, and the number of blocking time slots.

Literature Review

Laboratory plays a vital part in completing the learning destinations given to students, particularly in engineering education. Within the last two decades, inaccessible laboratories have created quickly. Based on the sort, research facilities can be categorized into four sorts, specifically "hands-on lab", "remote lab", "local simulation", and "virtual lab". A straightforward definition of remote research facility could be a physical research facility that can be controlled remotely by the client (Limpraptono et al., 2017) . In a study conducted by Orduna & Garcia-Zubia (2014) described that, the hardware and software architectures as a platform of a hybrid online laboratory developed at the TU Ilmenau. They adopted a dynamic booking system, such that resources are accessed dynamically, and a time slot is blocked, only if all the devices of the same type needed for the experiment are equipped. However, they did not consider different experiments that require multiple resources, and how resources are allocated to the users in that specific case, in order to minimize the number of blocked time slots. In an effort to minimize difficulties Henke, Nau & Wuttke (2021) developed an application that is used in evaluating the quality of their remote laboratory system.

System Architecture

In this section, the architecture of the laboratory learning system is proposed with the aim of minimizing the time slots' blocking rate for students acquiring experiments at the experiment reservation phase. In the proposed system architecture, a generalized physical infrastructure is considered, which reflects the flexibility of deploying the proposed laboratory learning system on any physical infrastructure. It also provides smooth integration between different laboratory infrastructures used in various fields at diverse spaces (e.g., An electronics laboratory can be integrated with a computer laboratory at different institutions (colleges, polytechnics, monotechnics and universities to be managed by the proposed laboratory learning system), which reflects its integrability and scalability.

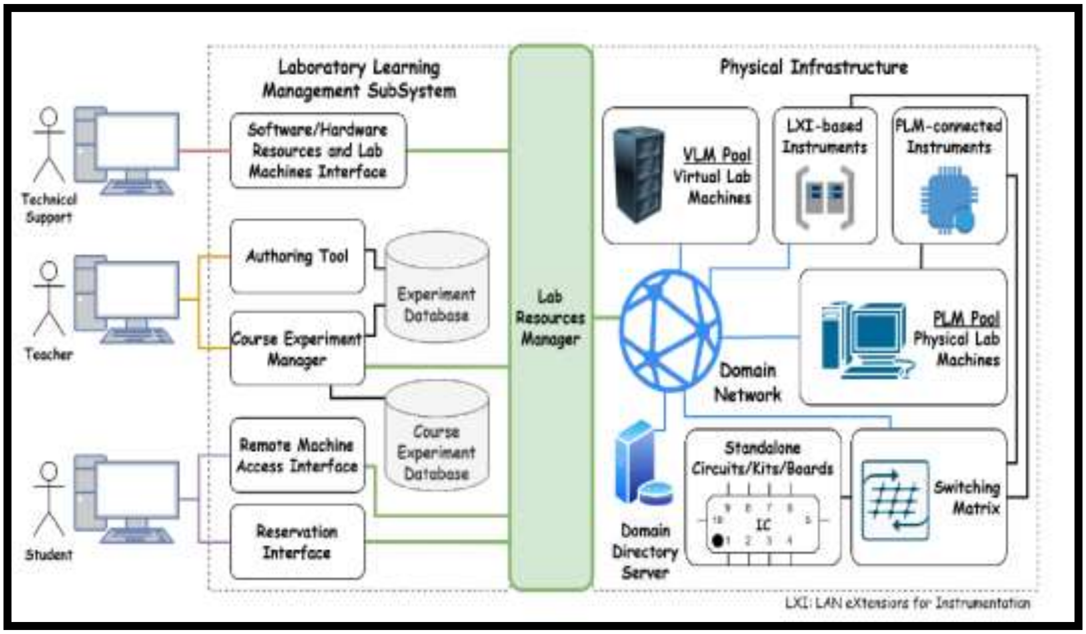

Figure 1: Proposing System Laboratory

Laboratory Learning Management Subsystem

The first subsystem in the proposed laboratory learning system is the laboratory learning management subsystem, which is the management software that helps teachers to create the laboratory learning object (experiment) and manage the way of experiment execution, it also provides an interface between the student and the physical resources, meanwhile, it allows technical support to manage the hardware and software resources. The laboratory learning management subsystem is composed of an *authoring tool*, *course experiment manager*, *remote machine access interface*, *reservation interface*, and *software/hardware resources and lab machine interface*.

The *authoring tool* which is the teachers' tool, it allows the teachers to create or edit experiments as a laboratory learning object, and store them in the *experiment database*. This includes the laboratory activities, contents, assessment, and evaluation mechanism. It also allows teachers to link an experiment to the required software resources (i.e., Matlab, Labview, … etc.) and hardware resources needed (i.e., LXI instruments, PLM connected instruments, standalone circuits, kits, boards, … etc.), which are already stored as available resources in the *software and hardware resources database*.

Laboratory Resource Manager

The second main component in the proposed laboratory learning system is the *Laboratory Resource Manager*. The *Laboratory Resource Manager* is considered the interface that connects the *laboratory learning management subsystem* with the physical infrastructure. It manages the physical infrastructure to ensure smooth and reliable students' connectivity to the remote laboratory. It provides an intelligent association mechanism, which aims at increasing the remote laboratory students' capacity, by minimizing the time slots blocking rate at the students' reservation phase and increasing the number of available time slots for reservation. Besides, it acts as a laboratory learning system decoupler, where it can be used as a standalone software that enables an intelligent management for diverse remote laboratory physical infrastructures, using different *laboratory learning management subsystem* designs.

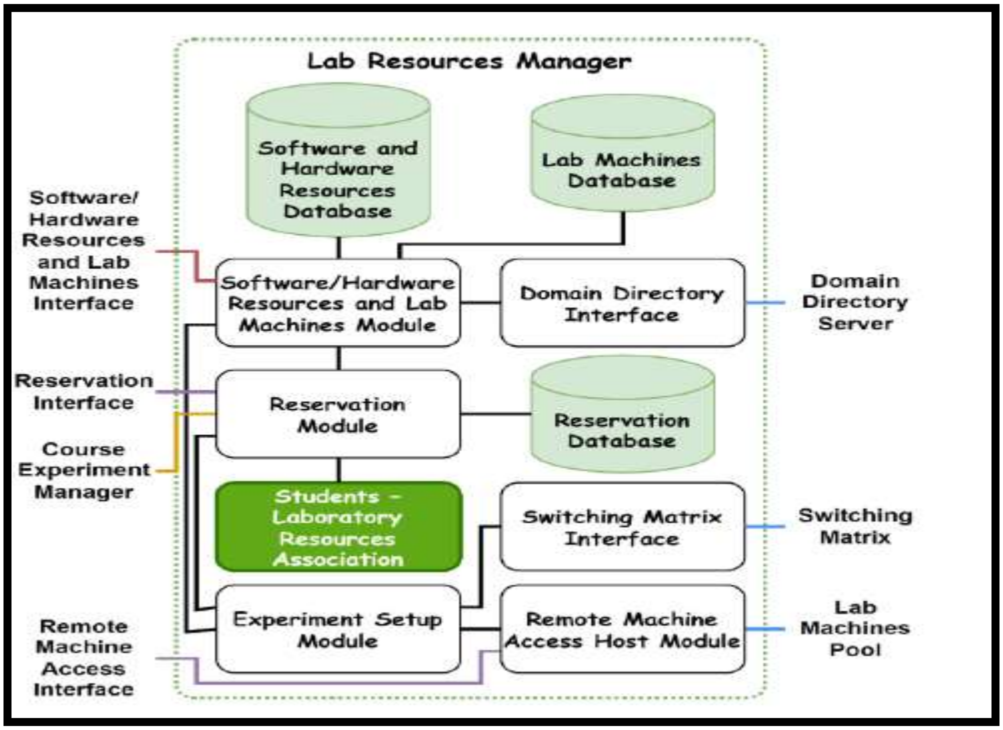

Figure 2: Main Components of the Laboratory Resource Manager

System Model

In this section, we propose a mathematical formulation for the presented system architecture. Let $\mathscr{M} = \{1,2, \ldots, m, \ldots, NM\}$ be the set of the available pool of laboratory virtual machines and physical machines, such that NM is the total number of virtual and physical machines.

Besides the virtual and physical machines, the laboratory available resources are comprised of different software and hardware instruments and can be denoted by the set $\mathscr{R} = \{1,2, \ldots, r, \ldots, N^R\}$, such that $N^R$is the number of available software and hardware resources, and $Nr\ \mathscr{M}$ is the number of physical and virtual machines that has resource r (e.g. software that can be installed on different physical or virtual machines with licenses, or hardware replicas that are connected to different physical or virtual machines). Hence, the total number of resources in the system is $N^{R}_{total} = \Sigma\ Nr\ NR\ \mathscr{M}\ r$=1 Also, the set of available resources for each machine $m \in \mathscr{M}$ are denoted by M$m \subseteq \mathscr{R}$, and $Nm\ R$ denotes the number of available resources in machine m.

Moreover, the created experiments are denoted by the set $\mathscr{E} = \{1,2, \ldots, e, \ldots NE\}$, where NE is the total number of created experiments. Each created experiment $e \in \mathscr{E}$ has a set of required resources E$e \subseteq \mathscr{R}$, such that there is at least a set M$m \supseteq$ Ee. Also, each experiment $e \in \mathscr{E}$ is assigned a duration time te from the set of available time durations $\mathcal{T}$ = {1,2, …, td, … , NT }, where NT is the total number of available time durations. Besides, $Ne\ Td$ is the number of time durations that can be reserved by a student for experiment e.

This number can be calculated by knowing the start scheduled time $Te\ start$ and due to scheduled time $Te\ due$ of the experiment, the virtual and physical machines' off-time duration for physical and virtual machines $tm\ OFF$, and the duration time te, as follow:

$$N_e^{Td} = \frac{(T_e^{due} - T_e^{start}) - t_m^{OFF}}{t_e}$$

On the other hand, the set of students reserving experiments at time slot t are denoted by St = {1,2, …, st, … NSt}, such that NSt is the total number of students reserving time slot t. an association matrix Xte at time slot t represents the association between the set of students St and the set of virtual and physical machines $\mathcal{M}$, such that X$t\ e$ is an NSt × NM matrix, and $NM \geq NSt$. An element of the matrix X$t\ e$ has the value of $xstm\ e$ ∈ {0,1}, where $xstm\ e$ = 1 represents the reservation of student st to machine m for experiment e, while $xstm\ e$ = 0 means that machine m is not reserved by student st for experiment e, this can be formulated mathematically as follow:

$$x_{s_t m}^e = \begin{cases} 1, & \mathrm{E}_e \subseteq \mathrm{M}_m, and \sum_{s_t} x_{s_t m}^e = 0 \\ 0, & \mathrm{E}_e \neq \mathrm{E}_e \cap \mathrm{M}_m, or \sum_{s_t} x_{s_t m}^e = 1 \end{cases}$$

student acquiring experiment e at time slot t that needs a duration time te is denoted by ste, such that ste ∉ St and ste = NSt + 1. The availability of time slot t for experiment e to be reserved by student ste is denoted by ate, and can be represented as follow:

$$a_t^e = \begin{cases} 1, & \sum_{s_t} \sum_m x_{s_t m} = N^{S_t} + 1 \\ 0, & \sum_{s_t} \sum_m x_{s_t m} < N^{S_t} + 1 \end{cases}$$

Where ate = 1 if all the reserved students St and the acquiring student ste for experiment e at time slot t are associated with machines from the machines pool $\mathcal{M}$. While ate = 0 if only some of the acquiring and reserved students are associated with machines from the machine pool $\mathcal{M}$.

The availability matrix Ae for any student acquiring experiment, e is an $NeTd$ × 1 matrix that contains the elements ate where t = [1, $NeTd$]. The number of available time slots $Nse\ A$ for student se is equal to:

$$N_{s^e}^{A} = \sum_{t=1}^{N_e^{Td}} a_t^e$$

While the number of blocked time slots $NsteB$ for student se can be calculated as follow:

$$N_{s^e}^{B} = N_e^{T_d} - N_{s^e}^{A}$$

In this work, our problem is to minimize the blocking rate which is defined as the number of blocked time slots per acquiring student, by optimizing the association matrix Xe between all the reserved students and the available physical and virtual machines at different time slots, where Xe = {X1e, X2 e, …, Xte, …, X $NeTde$}. This problem can be formulated as follow:

$$\text{OPT}: \min_{X^e} N_{s^e}^{B}$$

s.t.

$$x_{s_t m}^{e} \in \{0,1\},$$

$$x_{s_t m}^{e} = 1: \mathrm{E}_e \subseteq \mathrm{M}_m, and \sum_{s_t} x_{s_t m}^{e} = 0,$$

$$x_{s_t m}^{e} = 0: \mathrm{E}_e \neq \mathrm{E}_e \cap \mathrm{M}_m, or \sum_{s_t} x_{s_t m}^{e} = 1,$$

$$\sum_{m} x_{s_t m} \leq 1,$$

$$N^{S_t} \leq \sum_{m} \sum_{s_t} x_{s_t m} \leq N^{S_t} + 1,$$

In optimization problem OPT, constraint (7) ensures that the association index $xstm\ e$ is equal only to 0 or 1; and, constraint (8) and (9) ensures that a student is associated with a specific physical or virtual machine m, if only the machine can provide the experiment's required resources Ee , and no student is associated with this machine; Also, constrain (10) ensures that a student cannot associate with more than one machine; Moreover, constraint (11) ensures that at least all the reserved students in a specific time slot t are associated to physical or virtual machines.

Table 1: Proposed Matching- Game Algorithm

Algorithm 1 One-to-One Matching Game for Students Association

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Initialization: $\mathcal{S}_t$, $\mathcal{M}$.
Discovery and utility function computation:
1: Every student s_t^e construct $\succ_{s_t^e}$ using $U_{s_t^e}(m)$
Find stable Matching:
2: **While** $\sum_{\forall s_t, m} b_{s_t \to m} \neq 0$ **do:**
3: *For each unassociated student:*
4: Find $m = \arg\max_{m \in \succ_{s_t}} U_{s_t^e}(m)$.
5: Send a request $b_{s_t \to m} = 1$ to machine m.
6: *For all machines* ($m \in \mathcal{M}$)*:*
7: Update $\mathcal{S}_m^{req} \leftarrow \{s_t : b_{s_t \to n} = 1, s_t \in \mathcal{S}_t\}$.
8: Construct $\succ_m$ based on $U_m(s_t^e)$.
9: Accept $s_t = \arg\max_{s_t \in \succ_m} U_m(s_t^e)$.
10: Update $\mathcal{S}_m^{rej} \leftarrow \{\mathcal{S}_m^{req} \backslash \mathcal{S}_m\}$.
11: Remove machines $m \in \succ_{s_t^e}, \forall s_t^e \in \mathcal{S}_m^{rej}$
12: **end while**
13: **Result**: A stable matching μ^*.

Simulation Setup

In order to evaluate the performance of the proposed laboratory management system, a simulation setup is used where 5 experiments are created, and each experiment is assigned a unique resource randomly from the set of available resources. The students are randomly assigned one experiment from the created experiments in each iteration. In each simulation run, 1000 iterations are conducted, and average values of the iterations are calculated.

Moreover, two performance metrics are adopted to show the effectiveness of the proposed laboratory management system under different parameters changes. The first performance metric is the average percentage of blocked timeslots $Nse\ B\ Ne/Td$, which is the ratio of the number of blocked timeslots to the total number of available timeslots, where $0 \leq Nse\ B\ Ne/Td \leq 1$. The lower the percentage of blocked timeslots, the better the resource management scheme is.

Table 2: Simulation Parameters and Values

SIMULATION PARAMETERS	VALUES
Number of experiments N^E	5
Number of resources needed for an experiment $\|E_g\|$	1
Percentage of blocking vs numbers of students	
Number of machines N^M	5.15
Number of timeslots $N_e^{T\ d}$	10
Total number of resources in the system N^R total	25
Percentage of blocking vs number of machines	
Number of students N^s	40.80
Number of timeslots N_e^{T4}	10
Total number of resources in the system N^R total	25
Resources utilization efficiency vs number of machines	
Number of timeslots N^Td	1
Total number of resources in the system N^R total	25
Resources utilization efficiency vs total number of resources in the system	
Number of machines N^M	5.15
Number of timeslots $N_E^{T\ 4}$	1

Source: Laboratory report (2022)

The second performance metric is the average resource utilization efficiency, which is the ratio of the maximum number of students that can reserve in a specific timeslot to the total number of physical and virtual machines. Note that this performance metric also has a minimum of 0 and a maximum of 1. Whenever this ratio increases, this indicates the effectiveness of the used resource management scheme in utilizing the available resources.

In this context, and in order to evaluate the average percentage of blocking while increasing the number of students, we consider fixing the following parameters, the number of physical and virtual machines, the total number of timeslots, and the total number of resources in the system.

On the other hand, in order to evaluate the average percentage of blocking while increasing the number of machines, we consider fixing the total number of students, the total number of timeslots, and the total number of resources in the system parameters. Furthermore, to evaluate the average resource utilization efficiency while increasing the number of physical and virtual machines, we consider fixing the total number of timeslots, and the total number of resources in the system parameters. In addition, we fix the number of physical and virtual machines, and the total number of timeslots parameters in evaluating the average resource utilization efficiency while increasing the total number of resources in the system. A summary of the different parameters changes for each simulation run is presented in Table I. Moreover, a detailed explanation of how each physical and virtual machine is assigned its resources is described in the next subsection.

Simulation Results

In this subsection, we evaluate the performance of the proposed remote laboratory management system without the matching game framework, where a student's reservation to a physical or virtual machine for specific experiment is fixed (i.e., the student will be always associated to the same reserved machine until working the experiment). Then we will compare it with proposed remote laboratory management system while applying the matching game framework, where a student's reservation to a physical or virtual machine for specific experiment is dynamic (i.e., the student will be associated to any machine that is mapped to the needed resources for his experiment). Both the proposed remote laboratory management system with and without the matching game framework are compared to a third remote laboratory where each physical and virtual machine is assigned only one experiment, such that all the experiments are mapped to physical and virtual machines. In order to ease the comparing between the three remote laboratory management systems, the proposed remote laboratory management system without the matching game framework, which indicates a Fixed Student to Machine Reservation, will be denoted by

(FSMR). The proposed remote laboratory management system with matching game framework, which indicates a Matching Game based Resource Association, will be denoted by (MGRA). While the remote laboratory system where each physical and virtual machine is assigned only one experiment, which indicates a Fixed Resource to Machine Assignment, will be denoted by (FRMA).

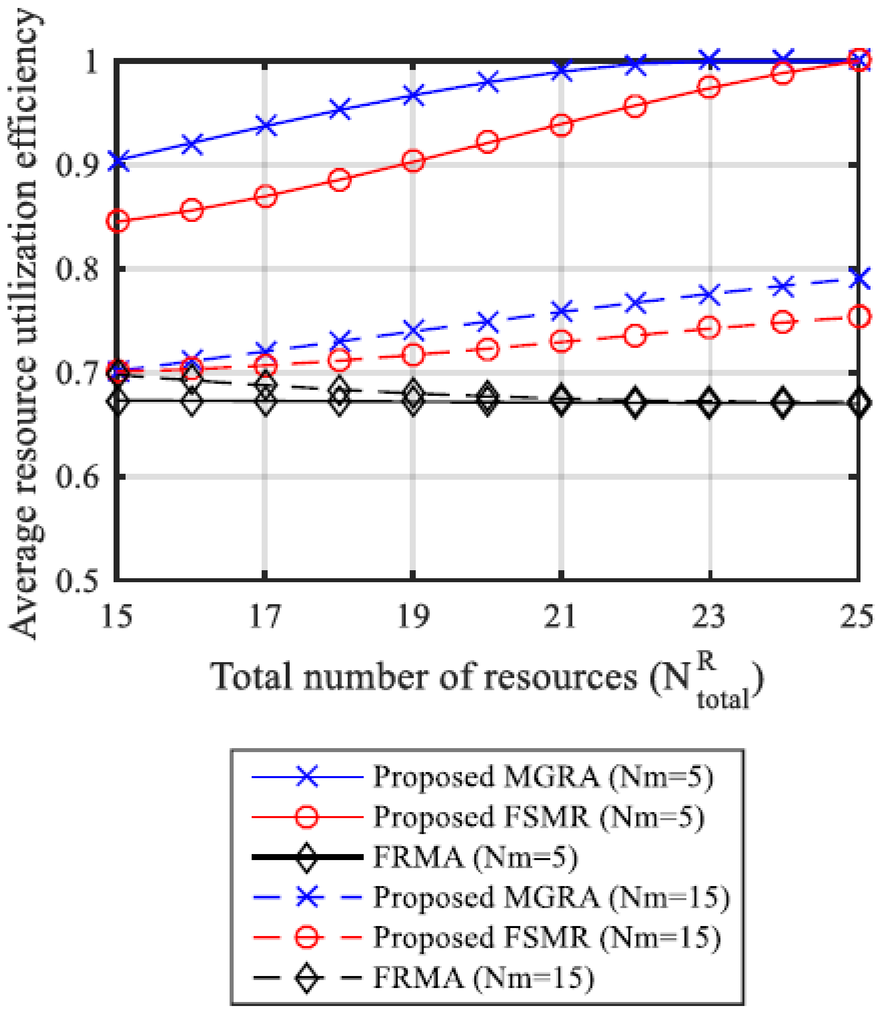

Figure 3: Resources utilization efficiency
Source: laboratories report (2022)

Table 3: Average resource utilization efficiency for different remote laboratory management schemes with the change in the total number of resources at number of machines = 5 and number of machines =15

Performance metric	***Different parameter***	***Difference parameter values***	***Stipulated parameter***	***Performance improvement percentage***		
				Expected FSMR & FRMA	***Expected MGRA & FRMA***	***Expected MGRA & FSMR***
Average resource utilization efficiency	**System resources I**	15	5	28%	32%	5%
	System resources II	25	5	50%	52%	2%
	System resources III	15	15	2%	1%	2%
	No. of machines I	25	15	12%	18%	5%
	No. of machines II	5	25	49%	49%	0%
	No. of machines III	12	25	16%	25%	8%
Average % blocked timeslots	**No. of students I**	15	25	12%	18%	5%
	No. of students I	10	5	100%	100%	0%
	No. of students II	35	5	81%	81%	0%
	No. of students III	50	5	0%	0%	0%
	No. of students IV	10	15	100%	100%	0%
	No. of students V	125	15	25%	46%	28%
	No. of students VI	150	15	0%	0%	0%
	No. of students VII	5	40	66%	66%	0%
	No. of students VIII	6	40	85%	91%	40%

Source: laboratory report (2022)

Generally, it can be shown that by increasing the number of machines the average percentage of blocked timeslots decreases for all the remote laboratory management schemes, since the machines' availability increases, hence increasing the capacity of students to machine association at one timeslot.

CONCLUSION & RECOMMENDATIONS

In this study, we proposed a laboratory learning system that provides flexibility, integrability, and scalability for deployment on multiple different physical infrastructures.

Moreover, formulated mathematical model for the laboratory learning system, which is followed by formulating an optimization problem that aims at minimizing the number of blocked time slots per acquiring student, by optimizing the association between the reserving students and the physical and virtual machines at different time slots, which reflects the maximization of the resources utilization. Then, a matching game-based framework was developed to optimally solve the aforementioned problem.

The performance of the proposed matching game framework was investigated. Simulation results showed the significance of the proposed matching game framework compared to other schemes on resources utilization efficiency, and the number of blocked time slots per acquiring student.

Based on the findings of the study the following recommendations were proffered:

In the future, plan to continue the approach of linking research on presence with research on learning from remote labs and from simulations. One particularly interesting question is whether it is possible to design simulations that capture the benefits of remote labs in terms of creating a sense of presence. The critical question will not be which learning environment is better, but how to maximize the potential of each to create the most effective learning environments possible. This line of research will be essential in informing the design and development of massive open online courses (MOOCs) and other new forms of online and blended learning.

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