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Optimizing Student Laboratories Through Lean Practices

– Comparative Analysis of Student Laboratories based on a Dual Degree Experience

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Opiskelijalaboratorioiden optimointi lean-periaatteiden avulla

- Vertailuanalyysi kaksoistutkintosopimuskoulujen opiskelijalaboratoriokäytänteiden välillä

Tämä opinnäytetyö käsittelee erovaisuuksia kahden kaksoistutkinto sopimuskoulun, IMC:n ja TUAS:n, välillä opiskelijalaboratoriokäytänteissä. Tutkimuksen ja vertailun tavoitteena on parantaa IMC:n Lääke- ja bioteknologia -linjan opiskelijalaboratorioita lean-filosofian periaatteita ja työkaluja hyödyntämällä. Nämä työkalut ja periaatteet ovat jo käytössä TUAS:n opetuslaboratorioissa.

Parannusehdotukset, joiden on tarkoitus tehostaa IMC:n opiskelijalaboratorioita, perustuvat kyselyihin, jotka teetin molemmissa oppilaitoksissa opiskelijoille ja henkilökunnalle, sekä molemmissa laboratorioympäristöissä työskennelleiden vaihto-opiskelijoiden haastatteluihin ja havaintoihin. Lisäksi opinnäytetyö sisältää kirjallisuuskatsauksen lean-filosofian historiaan, periaatteisiin ja työkaluihin sekä niiden käyttämiseen laboratorioympäristössä.

Työssä kerätty ja analysoitu data osoittaa, että suurimmat erot ja kehityskohteet IMC:ssä liittyvät laboratorioiden järjestykseen, opetustyyliin sekä dokumentointikäytänteihin. IMC:lle ehdotetut lean-työkalut ja -menetelmät ovat lean 5S-työkalu, VMS, Kaizen ja Kanban-menetelmät sekä GDP. Ehdotetut tehostamismenetelmät on selitetty siten, että opinnäytetyötä voidaan käyttää perustana opiskelijalaboratorioiden lean implementoinnin toteutussuunnitelmalle.

Asiasanat:

Lean laboratorio, opiskelijalaboratorio, lean-periaatteet, lean-työkalut, lean opetus, lean-filosofia

Bachelor’s Thesis | Abstract

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Optimizing Student Laboratories Through Lean Practices

- Comparative Analysis of Student Laboratories based on a Dual Degree Experience

This thesis dives into the differences in student laboratory practices between two dual degree agreement universities, IMC Krems and Turku University of Applied Sciences. The objective was to enhance the student laboratories of Medical and Pharmaceutical Biotechnology at IMC with the principles and tools of lean philosophy used in the Biotechnology and Chemical Engineering program at TUAS.

Suggestions to make IMC student laboratories more efficient are based on surveys conducted with students and staff at both universities, as well as interviews, and observations made by exchange students who have experience in both laboratory settings. A literature survey was also conducted on the usage of lean in student laboratories.

The data collected and analyzed in this thesis shows that the biggest differences and development points for IMC are in the organization of the laboratory space, documentation practices, and teaching style. Lean practices and tools to IMC were the lean 5S tool, VMS, Kaizen and Kanban methodology, and GDP. All the suggested practices were described and explained such that this thesis can be used as a basis for an implementation plan for student laboratories.

Keywords:

Lean principles, Lean tools, Laboratory Education, Student Laboratories, Lean implementation

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Abbreviations

CIP	Continuous Improvement Process
IMC	International Management Center Krems, University of Applied Sciences
TPS	Toyota Production System
TUAS	Turku University of Applied Sciences
VSM	Value Stream Mapping

1 Introduction

The subject for this thesis is the comparison of two dual degree agreement schools' (IMC and TUAS) student laboratory practices to better understand lean principles and tools in action. The main point is to find ways for IMC to implement lean philosophy into their student laboratories to make the laboratories work more efficiently. In addition, lean implementation to the student laboratories of IMC would give the students readiness to work in today's modern laboratories that have implemented lean tools for better organization, communication, and productivity in the workplace.

It is important to keep up with the standards of the industry and currently the laboratories of IMC's Medical- and Pharmaceutical Biotechnology -program do not fully reflect that. This is one of the reasons why I chose this subject for my thesis. I noticed a lot of differences in the teaching styles, organization and student friendliness of the laboratories when I was studying in IMC for a year for my dual degree. The stark contrast between TUAS and IMC was highlighted even more when I got a full-time job in a professional laboratory in Austria after my exchange year ended. My knowledge in lean-philosophy acquired from my studies at TUAS was a competitive edge when I was applying for jobs fresh out of school. This is something IMC student laboratories could easily offer to their students as well.

This thesis uses my own observations, exchange student observations in addition to surveys conducted to both schools' study programs students and staff as its main data and source. Furthermore, a literature review was conducted to the topic of lean philosophy, its history, tools, and practices and how all this would tie into laboratory environment and specifically in student or teaching laboratory. The literature review showed that there already had been some studies in the form of thesis to implement lean into professional laboratories and student laboratories. This was a great point for me to start and see how the implementation process varies between distinct types of laboratories. The interviews with the exchange students and surveys conducted for each school's students and staff cannot be seen as an objective source. In addition, my own observations are biased, and I had grown accustomed to certain types of student laboratory before I came to IMC from TUAS to study. However, the experiences of the individuals studying in said organizations are important to note and listen to, to be able to understand fully the experience from the point of view of a student in this environment. A better understanding and communication between the governing body (school and staff) and the students is a key part of the lean principles' constant development and therefore a significant source to be considered.

The hypothesis for this thesis is that lean implementation and the suggestions made here can make student laboratories work more efficiently, help the school save in resources such as time and workload of the staff and materials and equipment used in the laboratories. Additionally, these ideas would help to make the environment safer for the students to work in and they would give the students critical industry knowledge that is currently missing from the student laboratory experience in IMC’s Medical- and Pharmaceutical Biotechnology -program. The data and results collected will back up the literature reviews notion that lean principles will be an influential and substantial way to elevate the student laboratories at IMC.

This thesis will start with the literature review of what is lean at its core and where did it come from. Then I will open the most known and efficient lean principles and tools, what lean is in today’s industry and its pros and cons. I will end my literature review with a look at lean laboratories and lean in student laboratories. After the literature review, I will present my own observations, the results from the interviews of the exchange students and surveys conducted in IMC and TUAS. I will examine the results and data and make recommendations and suggestions or lean tools and principles that would be the most beneficial for specifically IMC’s student laboratories. I will end my thesis with a summary of the thesis and discuss the successful parts of the data collection. I will also review what did not work and what I would have done differently if I had the chance to start over with the thesis process.

2 Lean

The Lean principle has multiple definitions depending on the source and where the principle is implemented in. Most people know Lean from the manufacturing world, and how it can improve a manufacturing process efficiency immensely by eliminating components from processes that do not add any value to it. (Crawford 2016.) Lean can also be used in organizational management. Then it could be described as a leadership model that strives to the constant development of the company by minimizing things that cause waste or loss to the company. Lean can be explained in many ways, but all interpretations have one thing in common, maximizing efficiency, while still cutting resources. This is done by constant review of the working environment and work itself.

The philosophy of Lean could be applied to any number of businesses, productions, and organizations in any industry. It already works on a larger scale around the world, for example in the healthcare industry, but one could still use it to improve the workspace in the office. It was created for manufacturing operations by Toyota, but Lean is used worldwide in manufacturing, laboratories, team building and customer interactions. (Crawford 2016.)

2.1 History

To understand how to best utilize Lean, it is beneficial to learn, where and how Lean philosophy was created and by whom.

The idea behind Lean was born after second world war in Japan. Nations like Finland and Japan, who had to pay reparations to other countries after being in the losing side of the war and rebuild their own land, had little to spare when it came to resources in their country. These nations had to develop their economy fast and with minimal resources to keep up. This proved to be a great birthing ground for the philosophy that is behind Lean. (Pentti 2014.)

Lean is based in Toyota Motor Corporations production philosophy called Toyota Production System or short for TPS. The creator of TPS was Taiichi Ohno. The development of TPS started in the 1940s, because the company ran into difficulties with the lack of resources due to the war. They wanted to expand their car manufacturing industry, but Japan did not yet have the technology that the western countries possessed, so they had to get creative. (Hachemi 2019.)

In 1950 Toyota Motor Corporation send a representative to the United States to see how things are done there. This led to a breakthrough, when it was realized that in the United States, they had vast amounts of the products in their warehouses that were malfunctioning and needed to be fixed straight after the production. Toyota could not model their processing the same way, because they did not have the resources to a huge overproduction or to do things twice by fixing bad products like they did in the United States. Toyotas engineer also took inspiration from a shopping centers grocery stores way to organize and shelf products in the store for TPS's efficiency and streamlining their manufacturing. This is how Toyota decided to focus on flow efficiency during the production process. They started to manufacture products from order rather than have the products ready and waiting in warehouses. This led to shorter waiting periods between production phases and reduced the sizes of their warehouses. They also started to resolve problems that happened during production by stopping the manufacturing line and correcting the issue immediately which led to minimization of products that needed to be repaired after processing. (Hachemi 2019.)

2.2 Lean philosophy

Lean thinking is built around a few fundamental beliefs. First is that we can always learn more. Whether it is learning more about the processes, people or the working environment, knowledge and understanding results is the key for development. (Mikkonen 2022.) Utilizing Lean brings about constant development and growth, because one of the main thoughts in the philosophy is that all functions can be made more efficient and productive through problem solving. Constant development is one of the main pillars for Lean thinking. This constant development and looking for flaws inevitably lead to the pursuit of perfection and companies that have implemented Lean chase excellence and flawlessness in all areas of their functions. (Hachemi 2019.) The next point in the fundamental beliefs of Lean is the people around us and how we respect them. In a working environment people and especially the workers are your main asset for creating value for anything. In addition to workers, the customers' voice is extremely important to hear in a business. That is the reason business exists in the first place and if that is forgotten, the importance of the work done suffers. In addition, one particularly important principle in Lean is visualization. This concept will be opened more when I discuss how Lean philosophy is best implemented into a laboratory environment. However, visualization is crucial in Lean to give meaning and explanation to certain steps we take during processes which leads to better motivation for employees to truly go through all the needed phases of the operations. One essential part of Lean is how everything flows and moves. Here I mean the flow of processes and manufacturing, but also information and tasks. If something does not move efficiently enough, Lean strives to find out why and how to clear this blockage to optimize the procedure to the maximum extent possible. (Mikkonen 2022.) Streamlining is meant to produce an uninterrupted flow across the production chain.

2.2.1 Waste

Next question to comprehend the ideology further is how to recognize problem areas according to Lean. The Lean operating system heavily trusts in efficiency by identifying waste during production. By waste management the operations are streamlined and controlled to maximize productivity and performance. The Lean principle identifies and categorizes seven varieties of waste. (Koskinen

2011.) These are waste due to surplus production, inventory, repairs or rejects, unnecessary movement, excessive processing, delays or lag and transportation (Pentti 2014). Some sources also consider the wasted potential of an employee as an eight waste in Lean (Koskinen 2011). Another way of remembering the seven or eight principles of waste management is with the acronym DOWNTIME (Mettler-Toledo International Inc. 2023). This is represented in the table below.

Table 1: Acronym for the seven wastes of Lean (Mettler-Toledo International Inc. 2023)

D	Defects
O	Over production
W	Waiting time
N	Non-utilized employee talent or skills
T	Transport
I	Inventory
M	Motion
E	Excessive processing

Surplus production

Surplus or over production is where the whole TPS started. This means producing or supplying more than demand requires. (Koskinen 2011.) Negative consequences of surplus production are the unnecessary pressure on employees and equipment. This can lead to an excessively stressful work environment that can cause premature breakage of machinery, losses in employees or their morale and motivation. Additionally, over production leads to other wastes like oversized inventory, unnecessary movement between processes and transportational issues. Here supply and demand need to be in level with each other to avoid surplus production. Lean philosophy aims to identify causes for overproduction and to focus more on the demand of the customer. (Pentti 2014.)

Inventory

Oversized warehouses and inventory are a waste, according to Lean principle, that cannot usually be fully eliminated but must be managed to its minimum without compromising delivery accuracy of the products. Inventory waste increases the risk of malfunctions in the products, accidents happening and not being fully aware of what is in the warehouse. It in addition raises overhead costs and leads to other wastes like waste in transportation and unnecessary movement. One sure way to control oversized inventory is value stream mapping that helps the managers to see which practices are not that profitable from the customers' point of view. (Pentti 2014.)

Repairs and rejects

Investigating and repairing broken products and rejections increases the cost of errors and for obvious reasons does not make a profit from the work and hours that is put into them. Since the product already goes through the normal processing line in addition to the processes that go into fixing the issue in the product, net profit that would be made from the product after repair easily turns into net loss. That is the reason Lean philosophy considers this a waste that needs to be reduced by going through the processes to find what causes the breakage in the first place. This is also why in Lean it is considered more profitable to stop a production line to fix an issue right away. (Pentti 2014.)

Unnecessary movement

All unnecessary movements that do not add value to the process are considered a waste according to Lean (Koskinen 2011). Furthermore, if adding value with additional movement takes up needless resources, it would be considered a waste. Here it is important to recognize how the process works, what is needed for the process to be successful and to arrange the process in a way that all the equipment etc. are in a reach to avoid excessive motions during the process. Time that the inefficient movement devours also takes up revenue. (Pentti 2014.) Uninterrupted flow between phases can be achieved by thoroughly going through the placement of equipment so that the material flow is continuous and unbroken as well as short and as clear as possible between stages. This could be accomplished by reducing intermediate storage or distances between transportation. (Koskinen 2011.)

Excessive processing

An example of excessive processing or over processing would be if something is done following old plans that do not add value or purpose to the product. This results in misuse of resources like time and equipment. (Koskinen 2011.) Excessive processing might in worst case scenario produce a product that cannot anymore be used for its original purpose. This defeats the belief that one of Leans fundamental values is the customer and their demand. (Pentti 2014.)

Delays and lag

Delays, lags and waiting times between phases and procedures are a waste because this typically happens during working hours leading to economic loss for the company. In Lean this is solved with a Just-in-time system that like its name suggests times all necessary processes correctly and reduces waiting periods in between. This can be done for example by monitoring the flow rate of production or investing in new equipment. When evaluating waste due to delays, one must consider if reducing the waiting period is the most cost and resource efficient way or if this lag would be the best solution to begin with. (Pentti 2014.)

Transportation

Irrelevant transportation costs do not add revenue to the product and can lead to an increase in the price of the product. Lean urges to eliminate all unnecessary transportation between production phases to decrease the price of the product and other resources used. This serves the customer but also streamlines production and focuses resources where they are most needed in the company or organization. The layout of the manufacturing can reduce internal transportation. Usually, the simpler the layout the better it is for cutting down unnecessary transportation inside the company. (Koskinen 2011.)

2.3 Tools

The Lean principle cannot make anything more efficient or profitable. For that there is a ray of tools to utilize and to implement the philosophy for instance in a lab. The goal is to minimize the waste mentioned in the last chapter, streamline the processes, and recognize problem areas according to Lean. (Hachemi 2019.) In the next chapters I intend to elaborate on a few of the main tools to use when applying Lean guidelines into practice.

It is still essential to remember that the main way for a successful implementation of Lean is not the tools mentioned below, but open and honest communication between the floor workers and management. The tools of Lean bring out the issues in the processes, but to alter the working environment effectively and permanently, a plan of execution needs to be made and communicated to everyone. Communication between management and employees must be open and clear, thus motivating everyone to recognize and report issues, problems, and holes in the processes. This in addition brings easier acceptance of the new tactics and enforces Lean thinking further. (Hachemi 2019.)

Essential is also to take the right steps at the correct order. The first step is always to plan and simplify actions and procedures before reducing resources, otherwise the implementation might fail. (Hachemi 2019.) More on this later when I review the best ways and tools for implementing Lean principle in IMC student laboratories.

2.3.1 Lean 5S

Lean 5S is an organizational method for companies, organizations or even your worktable. 5S is five tier approach for applying and overseeing Lean philosophies belief of constant development, waste management and efficient and high-quality way of working into the operational area. The idea behind 5S is that waste recognition and oversight is easier in a well-planned and cleaned workplace. The 5 levels of 5S are sort, set in order, shine, standardize, and sustain seen also in the figure below. (Hachemi 2019.)

Picture 1: 5S phases, inspiration for the photo taken from https://www.5stoday.com/what-is-5s/

Sort

The first step in starting the 5S method is sorting. Sorting is an excellent place to begin because most companies or organizations have disarray inside them. Whether it is a physical mess of equipment lying around or having something as simple as a junk drawer, all this leads to redundant accumulation of things that are not useful or needed in the space or process. Clutter interrupts the normal and most efficient way of working in many ways. It is time consuming to find what you are looking for inside a mess. Disorder can also cause accidents in the workplace if things are lying around in the pathway of necessary movement. (Hachemi 2019.)

Sorting means going through all equipment and materials in the area where Lean is meant to be implemented in. Everything that does not add value to the product or process is meant to be tossed. This includes everything that is expired, broken or is not essential for the operations at hand. (Hachemi 2019.) To achieve accurate sorting, everything needs to be separated into three categories: useful, maybe and waste (Mikkonen 2022).

Important to note is that sorting does not happen in a day, especially in a laboratory environment, where all the equipment is not used daily. The first thing is to set up a timeline for the sorting. Choosing a timeline depends on the operations of the space being sorted, but a good rule of thumb would be 3 to 6 months in a laboratory environment. During sorting there is a quarantine area set up near the operational area. Everything that is broken or expired can be tossed right away. Other items considered to be in the waste category go to the quarantine area and they are given few days or weeks' time in there before they are also tossed. This allows time for other people to save the item if they need it during the sorting process. The equipment in the maybe-category is labelled and the labels are only removed if the items are used. If after some period the label still stays on, the item is moved to the waste category and therefore also to the quarantine area. (Mikkonen 2022.)

Set in order

The second S of 5S is Set in order. Everything has now been sorted out and needs to find its right place in the environment. There are two crucial parts to this phase and its success.

The first one is to think what is used the most and needs to be within reach and what is only used a couple of times a week, a month or even a year and can go further away from the workstation. The less equipment or material is used the further away it can be stored in the main working area. (Mikkonen 2022.)

The second part is visualization. Everyone working in the vicinity needs to know where everything goes to keep the area clean and organized. Ways to do this can be taping or painting places to the equipment, using color coding, labeling drawers to know what is in them, using QR- or barcodes just to name a few. The area should be visualized in such a way that if someone outside of the working area, who has never been there, came in, they would need to be able to find everything as easily as someone who works in the area daily. Also, storage spaces need the same visualization and organization. This helps to see if material or supply is running out before it is fully gone. (Mikkonen 2022) Visualization minimizes disorder and motivates workers to return tools and supplies to correct places after using them. This in addition lessens or eliminates the time used for looking for things during a process and reduces unnecessary movements between phases. (Hachemi 2019.)

Shine

The third S of 5S is all about cleaning. When this step is first introduced it is intended to leave a blank slate. However, this is not meant to be just a big cleaning step. It is also supposed to maintain the cleanliness of the workspace. Cleaning needs to become part of daily and weekly routines and a habit for all employees working in the area. (Hachemi 2019.) In this step it is essential to set instructions and criteria for cleaning to always reach the same level and to preserve the clean environment. This facilitates safe work setting and reduces near misses and accidents. One possibility is to take a photo of the area as it should look to set a standard and attach it to the workplace. In addition, questions like when to clean, what to clean and who cleans, should be answered by the end of the 3rd step. (Mikkonen 2022.)

Standardize

The fourth step is setting a standard and level for everyone to work towards. 5S method should not just be one-time organizational spring cleaning. The intention is to create a set of main principles that everyone follows. The standard should be the best feasible way of working. This can be changed afterwards if another method is seen to be more effective. (Mikkonen 2022.) Standardizing is essential because it is quite easy to slip into old habits over time if there is no accountability. Standardizing makes actions into habits and routines by changing the work structure supportively. It ensures that all of the staff know what their responsibilities are in their own workstation as well as in the general working area. Tools to maintaining the standard can range from pictures, videos, and visual guides to daily, weekly, or monthly checklists for the employees. (Hachemi 2019.)

Sustain

The last element of 5S dives more into sustaining the environment and routines. To make everyone understand the new ideology, the staff and visitors need to be trained, and regular checkups need to be admitted to routine by the staff and the management. (Hachemi 2019.) Auditing forms that everyone is liable to fill out are an excellent way to sustain the 5S method, but also to motivate everyone to follow the guidelines set (Mikkonen 2022).

It is important to note that this philosophy and method is flexible and open to change. If something is not working, it should be modified and adjusted. Everyone from staff and management are responsible for reporting issues and suggesting improvements. This aligns with one of the main pillars of Lean. Constant development is the only way to achieve the most efficient and reasonable way of working. (Hachemi 2019.)

2.3.2 Occupational safety and ergonomics

Lean 5S can be turned into 6S, when work safety is lifted into a bigger role. Safety has been introduced as the 6th S of lean tools especially in laboratory environments. When focusing on safety in the workplace the surroundings can be molded into a more efficient, sustainable, and stress-free environment for the workers. The core of this extra step in lean 5S is in mitigation. Risks are recognized and prevented beforehand, and safety analysis should be the primary focal point where all work and steps are started from. Risk analysis should be part of everyone's daily procedure. (Hachemi 2019.)

2.3.3 Lean six sigma

Lean Six Sigma is a combination of two methodologies, Lean Management and Six Sigma. Lean, as we already know, focuses on eliminating waste and refining efficiency. Six Sigma's main emphasis is in process perfection by optimizing process quality and minimizing errors during it. Put together, these methodologies streamline processes, boost customer satisfaction, and cut expenses. (What is Lean Six Sigma? 2024.) The gist of Lean Six Sigma is to eliminate errors and reduce variation and deviations during operations (Hachemi 2019).

Lean Six Sigma follows five stages during any type of process from laboratory work to a production line.

The first stage is *Define,* where a problem is identified. After that in stage two happens *Measuring.* It is meant to collect enough data of the problem for stage three when the results are *Analyzed*. When the analysis of the issue is done, a solution or I*mprovement* is suggested and applied to the problem. The solutions need to be *Controlled* certain number of times after the implementation to see that the issue is solved properly. This ensures that the improvements are sustained. (Lean Six Sigma Principles: Understanding the Core Elements 2022.)

Lean Six Sigma is a method very well suited for problem solving in a more specific way whereas Lean 5S recognizes and eliminates issues in a more comprehensive way. Lean Six Sigma tackles smaller issues one at a time. (Hachemi 2019.) Even though the scale difference is notable between Lean Six Sigma and 5S, both methods drive for the same goal and therefore are great tools to be used together rather than apart.

2.3.4 Kaizen

Kaizen as the name suggests is a Japanese business philosophy that strives for continuous improvement. The word kaizen means “change for the better” which also pretty much sums up the core of the ideology. Kaizen was also born in the after math of World War II and is more subtle approach for changes in the company to boost up efficiency, productivity, and quality of work. The goal is to pursue long-term improvements by activating everyone from ground floor workers to upper management to make systematic changes for the better. (Eliza Taylor 2022.)

One of the tools Kaizen uses is Value Stream Mapping (VSM). It is a way to see the flow of information, material or work that happens during a process. VSM is a visual representation of each step of the process, and it highlights the value-adding parts and the non-value adding activities. It helps to identify the pitfalls and areas of improvement. (What is Value Stream Mapping (VSM)? s.a.)

The VSM is started by creating a map of the current state of the operations or process. The map should have all the tasks, durations, and equipment for each stage. The more detailed the map is the easier it is to identify the bottleneck activities and non-value-adding parts of the process. (Kevin Hill 2019.)

Next stage would be to create an ideal future-state map. The map should keep the key principle of the function, but keep in mind the non-value-adding activities of the current state map. (Kevin Hill 2019.)

When both maps are ready the implementation part of the VSM starts. The goal is to have the reality to reflect the future-state map as much as possible. (Kevin Hill 2019.)

2.3.5 Kanban

Kanban is a planning tool that maximizes employee productivity by visualizing internal communication for everyone to see. It is a systematic and practical approach for minimizing waste coming from miscommunication and originates from lean manufacturing. Kanban is a Japanese word that translates directly to "sign" or "signal." True to its name, it is usually an actual sign, but it can also be some other form of visual communication, most commonly a board. Kanban is in addition one of the key tools used to reduce overproduction. It provides two main services to lean organizations: it acts as a communication system and as a tool for continuous improvement. (Hachemi 2019.)

An example of a Kanban in action would be a board that has tasks that are *up coming*, *in progress* and *done*. Also, a notable example could be signs left next to unfinished laboratory work when having a break or working elsewhere for a bit. This indicates to everyone that the unfinished project is left on the table intentionally and does not need to be removed or cleaned.

2.4 Lean today

In today's world, lean philosophies have been implemented in most industries from manufacturing to even finance. Lean has been changed from a Japanese philosophy to a global business stable and its principles and tools are used by industry giants like Amazon, Starbucks, and Nike. (James Gauci 2023.)

2.4.1 Pros

From the background and the core philosophy behind the principles of lean we can find multiple attractive reasons to implement lean into any workplace. One of the main indicators of the success of lean philosophy and tools can be seen by looking at the companies who have implemented it into their everyday processes and actions. It is known that these companies are commonly more successful than their competitors who do not use the same principles in their work philosophy. The lean operating model therefore increases companies' competitiveness. (Kauhanen 2022.)

One of the main benefits of proper lean implementation is waste reduction that often leads to an increase in efficiency. Particularly 5S as a lean tool decreases material waste and increases the usage time of certain tools and equipment. (Pentti 2014.) Unnecessary tasks and steps are cut to a minimum and space utilization is enhanced resulting in a more efficient and resource friendly way of working. The workflow becomes simpler and more understandable when the waste is eliminated, and this promotes a more stress-free working environment for everyone. (Kauhanen 2022.)

Lean operational model improves workplace organization with the usage of space and with visual tools, learning new practices comes more quickly than with other business model implementations. This is particularly shown with training of new employees or if the space has a lot of turn around with employees rather than just having a core staff working in the space. Equipment is more effortlessly found, and processes are learned faster when the work environment is visual. Visualization of the workplace also increases the knowledge of the stable staff. It is not just for the benefit of newcomers and changing personnel. Equality that comes from visual work environment can increase the motivation and happiness of the staff that works in the space every day. When tools and equipment are always in their assigned places and the cleaning of the space is divided to everyone equally, it can promote healthier co-worker relationships. (Pentti 2014.)

Understanding of the process and why we do certain things during it enhances employee engagement, decision-making and self-management. Lean helps everyone to see the purpose behind every task. (Pentti 2014.) The benefit of this is not just on the organizational level, but also on the individual level of the employees. It improves the staff's skill set and helps them recognize how their work matters in the big picture of the company. This is an effective way to increase flexibility and proactiveness amongst the team. In addition, the workers will be able to recognize wastes and faults in the processes they work with daily and bring them to the attention of the employer increasing the communication efficiency in the hierarchy of the company. (Kauhanen 2022.)

All the benefits of lean are linked together, and by increasing some parts it will cause a chain reaction and help in other parts of the processes. One inevitable chain reaction of the previously mentioned advantages is the enhancement of work safety. Lean philosophy and especially using the 5S tool will increase the safety of the workplace step by step. A clean and organized work environment decreases the chances of injuries and promotes a safe workplace. It will also cut costs in that front by lessening the chances for work accidents and injuries. (Kauhanen 2022.)

2.4.2 Cons

Changes in a workplace are usually complicated and sometimes even chaotic experiences for the employees and can cause resistance from the seasoned staff. Most big or small organizational changes fail due to lack of proper leadership during the change or improper communication during it. However, resistance to the change can also be constructive and allow the leaders an effective way to connect with the employees to discuss what change is necessary and why. Leaders need to justify and explain the changes, and this can expose uncertainties and flaws in the plan before implementation and help the employer in addition to see the side of the employee in the situation. (Hokkanen 2020.)

Implementation of lean takes a lot of time and resources and can become expensive to the company at first. It takes many resources to implement the agreed plan properly, but a lean working environment will pay itself back. Planning of the implementation takes time and rushing the process can cause more harm than good. (Pentti 2014.)

Improper training and communication during the process can result in employees reverting to the old ways and not sticking. This also depends on the employees' current satisfaction with the processes. If there are already complaints and dissatisfaction from the staff, change can be easier to explain. (Hokkanen 2020.)

2.4.3 Lean lab

Lean philosophy has been successfully applied in many industries and is currently increasingly being adapted to various laboratory environments. The focus of lean in laboratories differs a bit from processing facilities, but the main ideas and tools can be adapted to this environment as well. The focus is in optimizing the workspace for the best efficiency of sample analysis. The adaptation of the tools and principles tackle laboratory specific problems, like deviations in workloads and tasks, which differs from the original lean application to production setting where automation of processes is more a possibility. The demand and workload fluctuate more and can be unpredictable at times and can lead to poor turnaround times during peak seasons and extremely low productivity in slow periods. (Hachemi 2019.)

Lean laboratories optimization can be achieved by eliminating waste and especially time-wasting steps in workflows (Mettler-Toledo International Inc. 2023). The aim is increasing speed of processes and decreasing costs and recourses through improving productivity, minimizing rework and investigations, fostering continuous improvement and innovation culture in the workplace and balancing between standardized and flexible laboratory design. (Kevin Hill 2019.)

When planning a lean implementation to a laboratory setting there are certain important fields of improvement that have been identified by Mettler Toledo that work especially well in lean laboratory concept. Mettler Toledo has a lean lab guide for laboratories that consider or are implementing lean into their laboratory environment. This guide includes a checklist of the fields of improvement seen below. (Mettler-Toledo International Inc. 2023.)

- Housekeeping and workplace optimization with 5S
- Value stream mapping for process analysis
- Workload
- Laboratory workflow
- Performance management
- Laboratory equipment
- Skills of laboratory personnel
- Laboratory chemicals / auxiliary material (KANBAN)
- Continuous Improvement Processes (CIP)

This checklist gives a great overview of the areas that need to be reviewed for improvements in a laboratory setting. In a lean laboratory the best tools to review these areas of improvement are VSM, visual workplace, work cell specimen processing, lean 5S that also includes the 6^{th} S aka. safety and Kanban. (Kevin Hill 2019.)

Lean 5S improves safety and productivity throughout the five main stages of the tool. It helps to improve housekeeping and workplace optimization in addition to the workflow and workload of the laboratory. This can also be seen in work cell specimen processing where testing and processing equipment is organized in a way that minimizes movement, reduces setup time, and improves safety. (Kevin Hill 2019.)

VSM supports the 5S tool by helping to identify waste throughout the current processes. It also helps to increase workflow efficiency by designing better and more ideal future processes for the laboratory. (Kevin Hill 2019.)

Visual workplace and Kanban go hand in hand improving the communication in the laboratory between personnel, the skills of the staff and keeping track of the materials, equipment and chemicals in the laboratory (Kevin Hill 2019).

2.4.4 Lean in a student laboratory

Lean laboratories are also part of companies that are trying to make a profit. In a student laboratory, efficiency is not due to profitability or meeting customer deadlines but to cut costs and manage the time usage of the staff and students during experiments. In an educational setting lean principles are meant to simplify and clarify the operations for the students and the staff. Organized laboratory environment will enhance student safety and learning. However, it is notable that applying lean philosophies and tools into student laboratories involves more than organizing the space and the processes. The implementation also needs changes to teaching methods and laboratory scheduling to accommodate space constraints and the needs of students and staff. If there are too many constraints in educational spaces this could lead to the principles not being effective enough. (Hachemi 2019.)

The needs of the educational system versus students and staff need to be fully considered while planning the space and processes to work with lean implementations in mind. What works in a different laboratory might not be what is best for you due to the difference in size of the laboratories or student groups, deviations in educational program and experiments or what you want to achieve with the changes. In the next chapter I will try to map out the differences of the current laboratories in IMC and compare them to the laboratories in TUAS to achieve an understanding of the needs of the students. This will help to draw a picture of the needs of the student laboratories in IMC and the possible changes IMC can implement to the organizational parts of the laboratories in addition to changes in study program and teaching methods to help the students to get most out of the student laboratory experiments.

3 Observations

Through observations of my own, interviewing other dual degree students from both IMC and TUAS and conducting surveys to both schools students and staff, I intend to map out some of the ways lean philosophies and tools could be used in IMC’s student laboratories to make them more efficient and resource friendly to the students and the staff. The interviews and surveys were done anonymously and are based on firsthand experiences and views but can be helpful in getting ideas of what could be done differently in IMC. These results and suggestions can be taken as guidelines for the implementation process of lean principles and tools.

3.1 Dual degree students interviews and own observations

The initial inspiration and idea for my thesis subject came from my first laboratory classes as an exchange student in IMC. I often felt quite disoriented and lost during experiments, because at TUAS I was accustomed to lean philosophies being implemented into the studies. The approaches of each experiment in TUAS required more planning and understanding of underlying methods and more work from the student's point of view than in IMC. I noticed that I implemented some of the practices in the way I did experiments in IMC student laboratories and because of that I was often done earlier with my experiments. One of the main differences I noticed between the dual degree partner schools was the lack of documentation during experiments and the way staff or professors prepared everything from equipment’s to materials for us before the start of the experiment. This was very time saving but also made me feel like I did not need to know, for example, how an ELISA reader etc. worked, because everything was set up for me already. I noticed I adapted to the IMC laboratory quickly and started working independently like they had taught us in TUAS. I started wondering if these observations and experiences were just my way of seeing the differences between TUAS and IMC or did the other dual degree and exchange students notice similar differences. I started discussions with my peers who studied in IMC and TUAS student laboratories and started developing the idea for the thesis based on these observations.

I conducted 4 different interviews with 4 different dual degree students. Three of the students were originally from TUAS and were exchange students in IMC and one student was from IMC and had her exchange year in TUAS. For the clarity of the answers from the interviews and to keep the interviewees' identities anonymous I will address the students as *TUAS student 1*, *TUAS student 2*, *TUAS student 3* and *IMC student 1*. Next chapters are going to open more of my and the other students' observations of the differences between IMC and TUAS student laboratories.

Organizational differences and lean principles

The level of organization, particularly the application of lean principles and tools at TUAS, was one of the most striking differences between the two schools noticed by the students interviewed and me. TUAS' detailed markings, label usage, and other visual cues such as blue taping to cupboards, shelves and tables are a prime example of the lean methodology utilized by TUAS in their student laboratories. These visualized managing systems align with the lean 5S principles, *sort, set in order, shine, standardize,* and *sustain* and are designed to create a more organized and efficient working environment for the students and the staff. The systematic placement of equipment and materials ensures that everything in the laboratory has a designated spot making it easier for the students to find things and maintain cleanliness more independently.

In contrast, IMC does not have these kinds of visual aids implemented in their student laboratories at least to same extent that it is in TUAS, resulting in a less organized workspace. Both *IMC student 1* and *TUAS student 1* noted that this major difference made it more challenging for them to independently locate equipment and materials at IMC’s laboratories particularly when they were still unfamiliar with the environment.

The lack of clear markings and structured organization in the laboratory can lead to inefficiencies and confusion, especially for new students and exchange students not yet familiar with the laboratory's setting. Proper lean 5S markings could make a difference in students' way to adapt quicker to the laboratory environment of IMC and could also make training new students easier. If IMC were to adopt similar approach to TUAS in lean visual management practices it would in addition promote more independent way of working for the students and could decrease the preparation time needed from the staff or professors for each experiment. Clear visual markings and instructions on equipment, for example with QR-codes with instructions on how to use certain devices in the laboratory could streamline workflows, reduce downtime, and increase efficiency of each laboratory session. *TUAS students 1* and *3* both agreed that such changes could make IMC laboratories more user and student friendly and make the experiments less confusing, especially to new students.

Student autonomy and responsibility

Another major deviation noticed by the interviewed students between the two schools lies in the level of autonomy and responsibility given to the students. *TUAS students 1* and *3* felt that TUAS expects its students to take a more proactive role in their experiments compared to IMC’s expectations. In TUAS the emphasis is on self-management during the experiments and *TUAS student 1* and *IMC student 1* noticed this especially in the way students at TUAS are required to gather their own materials and equipment needed and prepare the proper laboratory set up for the experiment. In addition, students in TUAS are required to take responsibility for cleaning and restocking common items like pipette tips or distilled water after themselves. *TUAS student 1 and 2 noted that the assignment of designated operator pair for each laboratory session ensures that the laboratory is returned to its original state after use by the students and takes some workload off the staff and professors.* This reinforces the shared responsibility concept originating from lean philosophy. *TUAS student 1* mentioned that at TUAS each laboratory day has designated operators from the students that have a checklist of things to clean and check before they leave the laboratory. Operators are always the last to leave and they make sure the laboratory is equipped the same way as it was when the experiment started. Also, students each take turns to do monthly monitoring that all agreed lean 5S principles are followed. If there is new equipment a place is found and marked for it or if some materials are about to run out or they are not in their correct places, it is rectified. This is how everyone who uses the laboratories takes responsibility, lessening the staff's workload and releases resources to use.

The interviewed students noted that IMC laboratories in contrast operate in a more structured and staff-prepared manner. Most of the time the staff in IMC sets up everything ready for the students for their experiments beforehand. The students interviewed agreed that this can save time during the experiment but may limit the students' opportunities to learn organizational and preparatory skills that are also important after graduation. The approaches in teaching styles differ because TUAS values and teaches more skills that prepare the students for work life, and IMC could be more focused on the academical and theoretical part of the experiments and teaching. *TUAS student 3* agreed that TUAS prepares the students more to working environments of today and that IMC has higher education in mind with focusing on academical parts of the laboratories and saving time with skipping over the practical parts of laboratory work like planning and prepping for the experiments and cleaning afterwards. *IMC student 1* argued that it took more time to do the experiments when everything was not ready for you like in IMC. She said that in TUAS the students need more time to do the experiments, but that the staff or professors do not need as much time to prepare the student laboratories beforehand. While IMC’s approach is more straightforward and can make laboratory sessions faster, it can reduce the students’ exposure to the practical parts of lab work, such as planning the experiments and equipment management and maintenance, which are crucial skills when working in an actual laboratory. *TUAS student 3* noted that lack of these skills can be a con when applying for work after graduation.

Documentation and reporting practices

Another key factor in overall student experience for the interviewed students was the differences in documentation during experiments and reporting practices in TUAS and IMC. At TUAS, students are required to keep a laboratory notebook that aligns with Good Documentation Practice (GDP). *TUAS student 1* explained that GDP in TUAS includes precise guidelines on how the notes should be taken during the experiments and what should be included in the notes. She listed examples such as only using ballpoint pens, keeping visible corrections, and keeping clear structure in the notebook with margins, page numbers and table of contents. Also, everything that differs from the protocol provided by the professor and precise measurements should be noted down in the lab journal, to promote reproducibility of the experiment. *IMC student 1* and *TUAS student 3* agreed that while this level of detailed writing during the experiment is very time consuming and may seem boresome to students, it ensures that the data produced is reliable, troubleshooting afterwards is easier and drafting a report is quicker. *TUAS student 2* commented that IMC's approach seems more relaxed and has less emphasis on detailed lab notes or reports. *IMC student 1* remarked that this would often make writing of the report and understanding of the results more challenging as there would be fewer reference points. In a professional context, *TUAS student 3* highlighted the importance of GDP in the replication of experiments and verifying one's results, which is a critical aspect of scientific research and assuring quality the laboratory experiments made. Learning proper GDP prepares the students for industry standards where such practices are usually the norm. While *TUAS student 2* saw the rigorous approach to documentation in TUAS labor-intensive and tiresome, *TUAS student 1* argued that GDP allows deeper understanding of the experiments and teaches students the importance of record-keeping. This skill is highly valued in both industrial laboratory settings and in research. On the other hand, IMC's approach allows the students to learn by doing what needs to be documented from each experiment to write a good report of it. IMC's way might also be faster and streamline the students experience compared to TUAS's approach. *IMC student 1* and *TUAS student 2* both agreed that the reports were easier in IMC compared to TUAS. *TUAS student 1* commented as well that there was not really a comprehensive guide on how to write a report in IMC and it differed a lot based on the professor and course in hand. This could be a major issue to some workplaces if the graduated students do not know how to draft full reports on their experiments.

Summary of the student's laboratory experiences

In summary, the primary differences between TUAS and IMC in the student laboratories can be divided into organization, workflow and focus areas.

The students described IMC's laboratories as easier and faster to work in due to the streamlining of some of the preparation work and cleaning. However, most also agreed that the lack of organizational structure and GDP requirements may hinder the development of practical lab skills and reduce students' readiness for industry roles and life after graduation.

Interviewed students mostly agreed that TUAS's emphasis on lean principles, student self-management, reporting and GDP makes the experience in the laboratories more time-consuming. Some of them, however, noted that this makes them feel more prepared for the realities of working in a professional laboratory environment after graduation. TUAS taught them crucial skills in problem solving, organization and taking accountability in one's work.

The interviews suggest that IMC's current approach prioritizes efficiency and might have a more relaxed approach focusing on the theoretical knowledge compared to TUAS's emphasis on hands-on skills and preparing for work-life. The differences reflect also more broader differences in educational philosophies TUAS leaning more towards industry readiness and practical training and IMC having more emphasis on academic learning and therefore streamlining some parts of the laboratory sessions. These interviews show how different educational approaches in the practical student laboratories shape the skills and preparedness of students also for their future careers.

3.2 Survey results

The surveys were conducted on the Microsoft Forms platform and were the same for the students of IMC and TUAS and staff of IMC and TUAS except for the survey's language. All answers were anonymously collected from IMC's Medical and Pharmaceutical Biotechnology study programs and TUAS' Biotechnology and Chemical Engineering study programs students and staff via email link to the survey platform. All four surveys are attached to this thesis as attachments and answers were sorted, cleaned, and evaluated with Excel by the main researcher of the thesis and the thesis instructor, Kari Haajanen (TUAS). Attachment 1 shows the questions for the students of IMC and TUAS and Attachment 2 shows the questions for the staff of IMC and TUAS.

From IMC 87 students and 2 staff members participated in the surveys. Unfortunately, I could not get hold of more staff members from IMC to participate in the survey and that will be reflected in the evaluation and conclusions of the results. At TUAS 47 students and 5 staff members participated in the surveys.

Since the number of responses differed between the schools, the results will be presented as percentages to account for easier understanding and comparability.

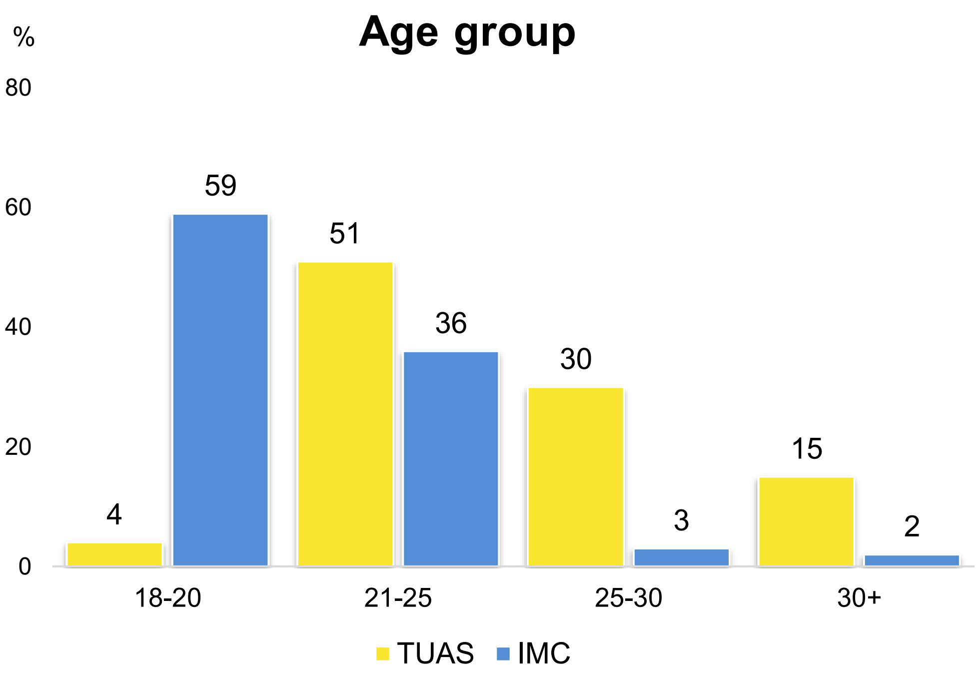
3.2.1 Students

Questions for IMC's and TUAS' students can be seen in Attachment 1.

Demographics

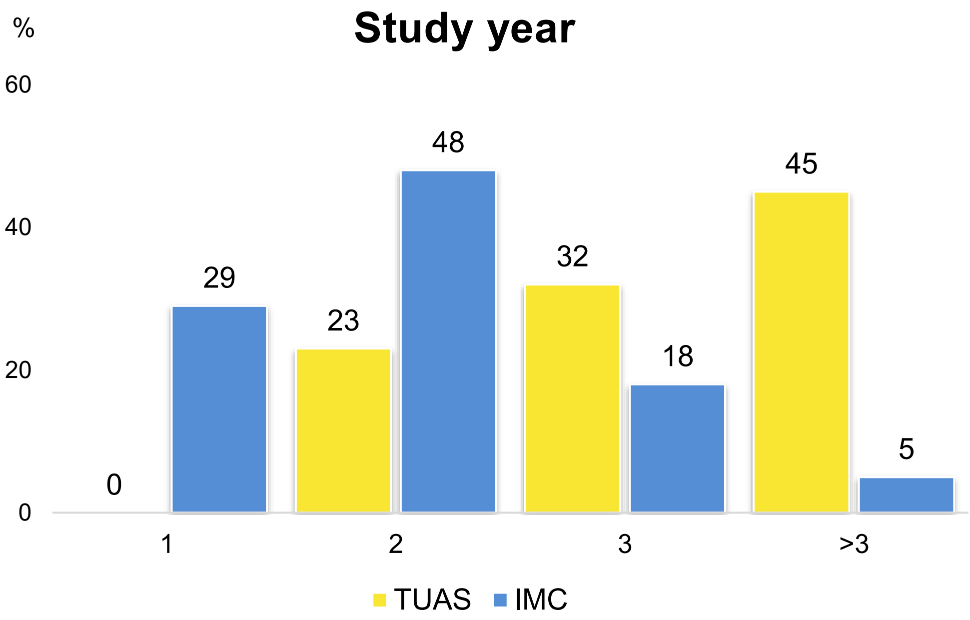
Seen from Figure 1 below over half (59%) of the respondents from IMC were 20 years or younger. In comparison, at TUAS, the majority (51%) of the students who participated fell into the age group of 21-25 years.

Figure 1: Comparison of the age of students who participated in the survey.



Differences in the academic year of study can also be observed from Figure 2 below. Most IMC students were either 2nd (48%) or 1st year (29%) students. In contrast most of the responses in TUAS came from students that were in their 3rd academic year (32%) or beyond that (45%).

Figure 2: Comparison of the academic year of study of the students who participated in the survey.

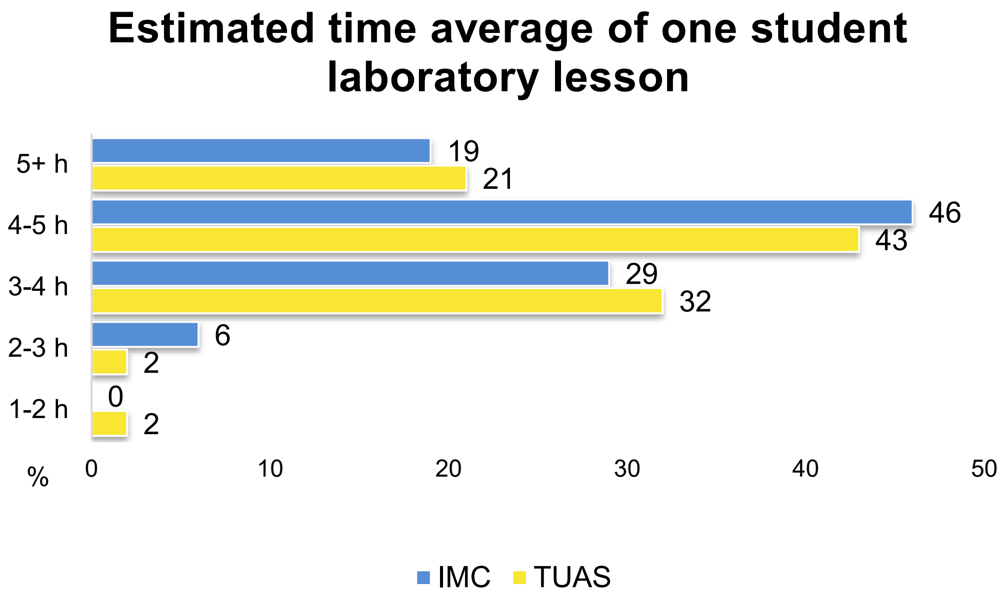


Student laboratories

Duration on laboratory sessions and professors initial briefing before the sessions

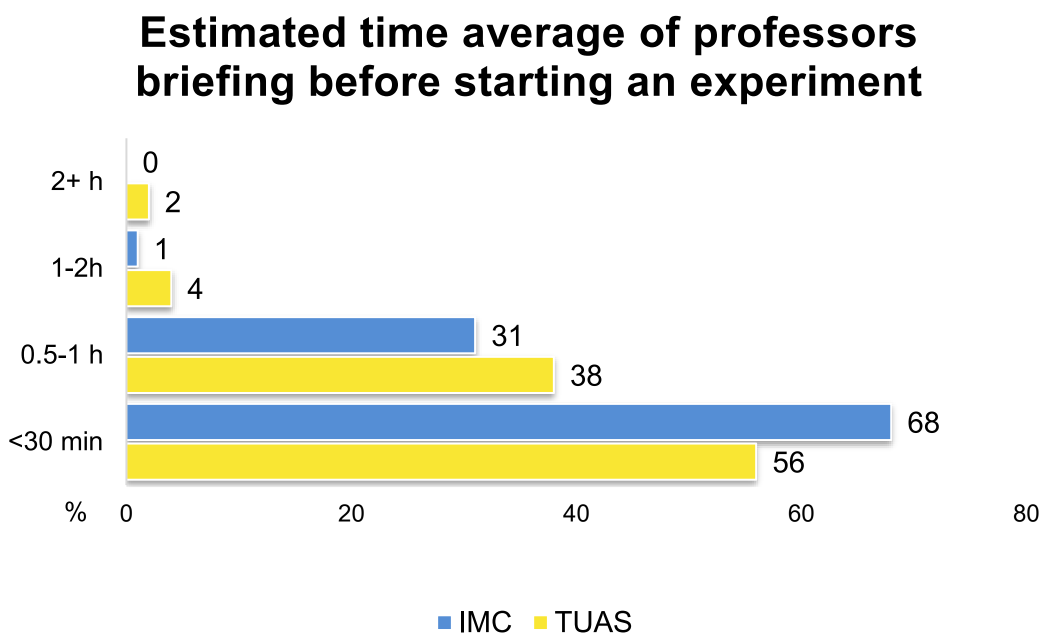
In both IMC and TUAS, most students reported the estimation of their laboratory lessons to be typically around 4-5 hours. At IMC 46% respondents answered this as their estimation, whereas 43% of TUAS students had the same estimation. From Figure 3 below we can observe that the estimations between the students of IMC and TUAS are matching nicely with just slight differences.

Figure 3: Results from the question: "How long does an average student laboratory lesson last? (an estimate)".



The estimations of how long professor briefings lasted before the experiments could start in the student laboratories had the same trend of similar responses from IMC compared to TUAS students. At IMC, the most common answer with 68% was that the duration of the briefings usually lasted under 30 minutes. With TUAS students the number was 56% with a clear majority. The second most common answer from both schools was 30 minutes to an hour. These results can be seen from Figure 4 below.

Figure 4: Results from the question: "Estimate how long does it usually take that you to start your experiment, and the professor's briefing is over.".



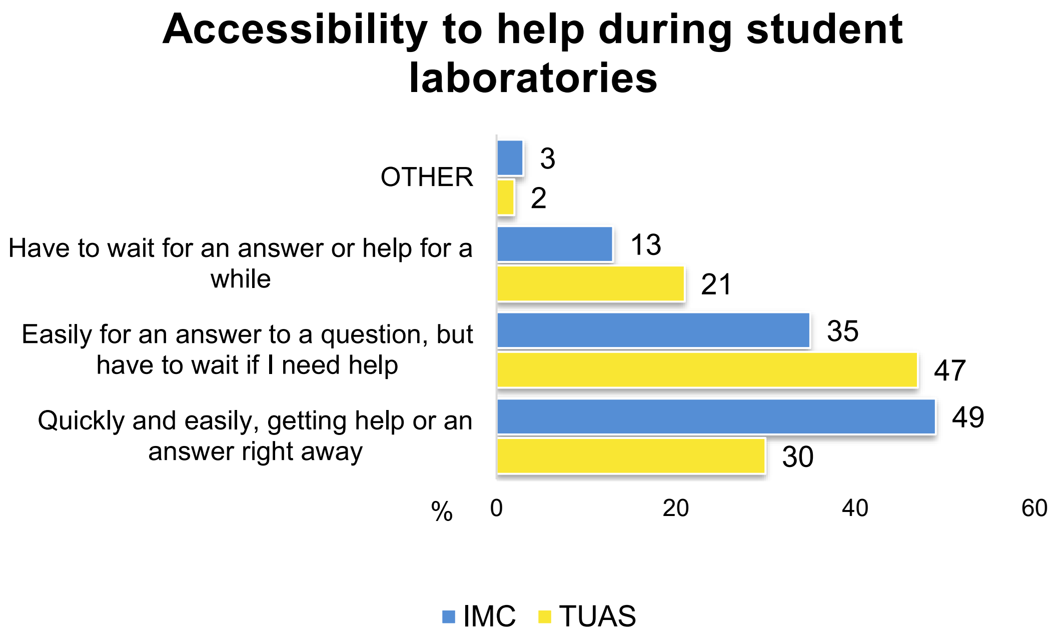
Accessibility of support during student laboratories and laboratory organization

Next set of data in Figure 5 below examines the students experience of the availability of support during the laboratory lessons in IMC and TUAS.

IMC students mostly were happy about how easily they got help physically during the experiments and obtaining answers regarding the experiment with 49% feeling this way. 35% of IMC students answered that they had to wait for hands-on assistance from the professor but got right away an answer to their questions. Three students commented in the open-ended response saying that there is quite a lot of variability in teaching methods between the professors, with some instructors being more hands-on and others responding to questions with more questions to help the students to reflect on the situation themselves.

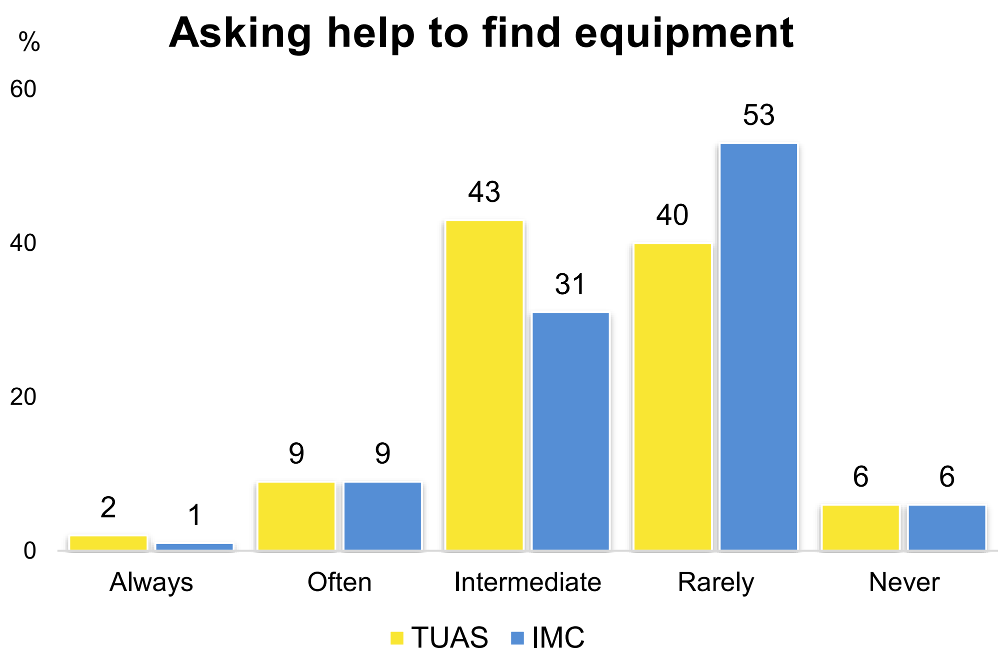
In TUAS the students perceived that the assistance that professors offered is less hands-on. 47% of students reported that they easily receive answers but not physical help from the staff and 30% found it easy to get answers and assistance. From the open-ended question, it became clear that the instructors in TUAS expect thorough preparation for the experiment beforehand from the students, leaving students responsible for executing tasks more independently.

Figure 5: Answers to the question "How easily can you ask the teacher for help or a question during the experiment?"



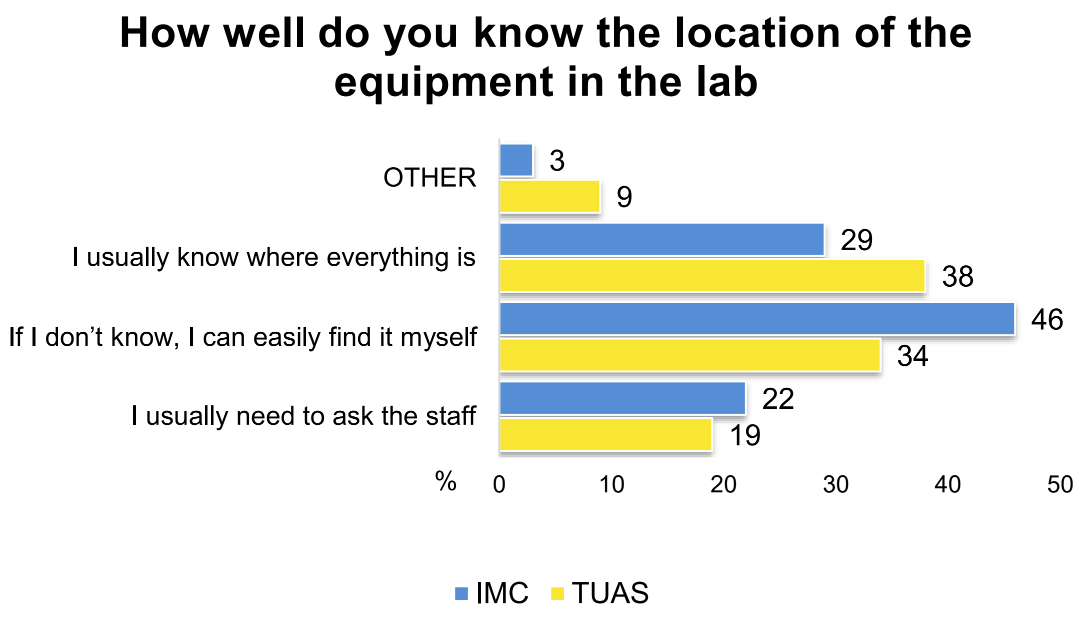
In both IMC and TUAS students feel like they are familiar with the location of equipment in the student laboratories seen from Figure 6 below, although some comments about laboratory organization were made. At IMC 53% of students reported rarely needing help in finding equipment compared to 40% at TUAS. In comparison most students at TUAS selected “intermediate” as their answer (43%), which reflects a little more assistance needed in locating everything in the laboratory. Answers between intermediate and rarely had minor differences in both institutes.

Figure 6: Answers to the question: "How often do you have to ask the professor, where needed equipment for the experiment is located?".



Results from Figure 7 below show that TUAS students are more familiar with their laboratory with 38% knowing where all the equipment is located compared to IMC's 29%. Both IMC and TUAS students noted in the open-ended answer that if some more advanced equipment is needed for the experiment, professors or peers help is usually needed in the locating of it.

Figure 7: Answers to the question: "How well do you know where everything in the laboratory/laboratory building is (tools, reagents, machines etc.)?".



Preparation for student laboratories

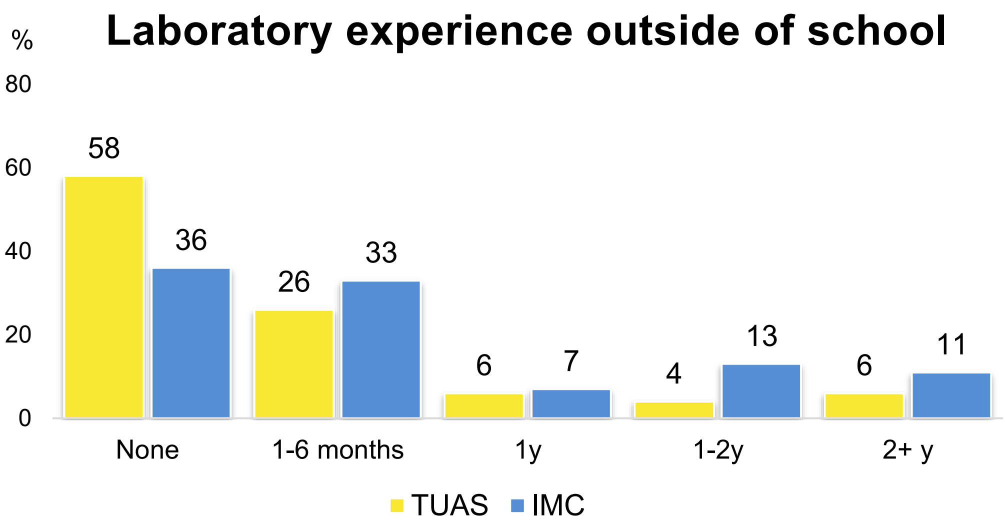
For multiple choice question, “What do you usually do to prepare for laboratory experiments at IMC/TUAS?”, the combination with most answers from IMC were “Reading through the protocol beforehand” linked with ” Answer pre-assigned questions set by the professor” and “Make notes to the protocol/workflow/own notebook about the experiment” with 38%. A close second was the combination of just “Reading through the protocol beforehand” linked with ”Answer pre-assigned questions set by the professor”. In TUAS 34% of the participants answered the first combination as well and 38% the second combination with the second being slightly more popular. Notably five IMC students commented that they also like to watch videos from the internet about the experiments beforehand to prepare for it. Only one student from TUAS commented about watching videos about the experiment.

Lean knowledge and working outside of student laboratories

Working outside of student laboratories

Most common answer to this question from both institutes was that students have no laboratory experience outside of student laboratories. At TUAS, 58% had no experience, and 26% reported 1–6 months experience outside of student labs. Similarly at IMC, 36% of respondents indicated no prior lab experience, while 33% reported 1–6 months of experience. These results can be observed from Figure 8 below.

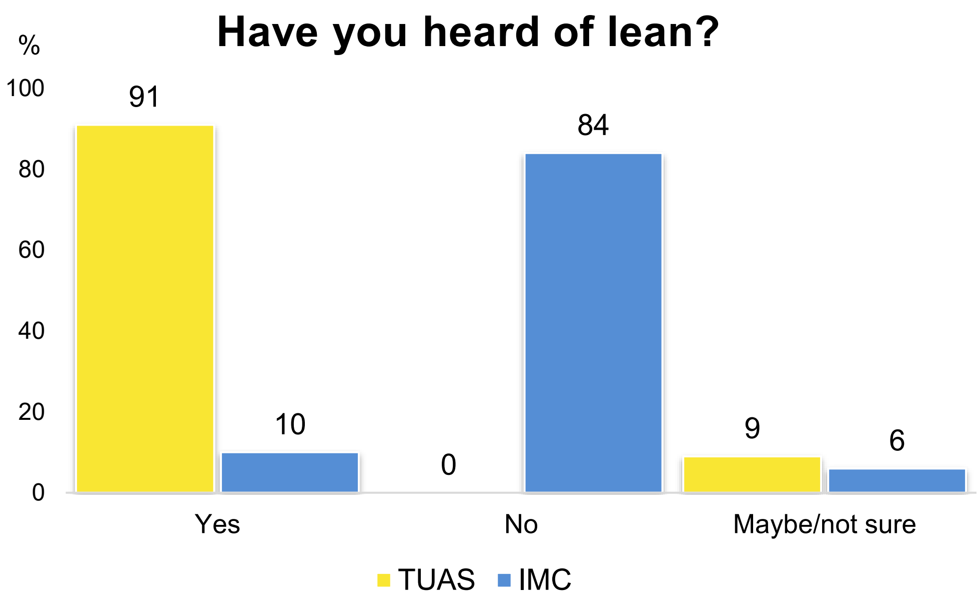
Figure 8: Answers to the question: "How much do you have working experience in a laboratory? (school laboratories excluded)".



Lean knowledge

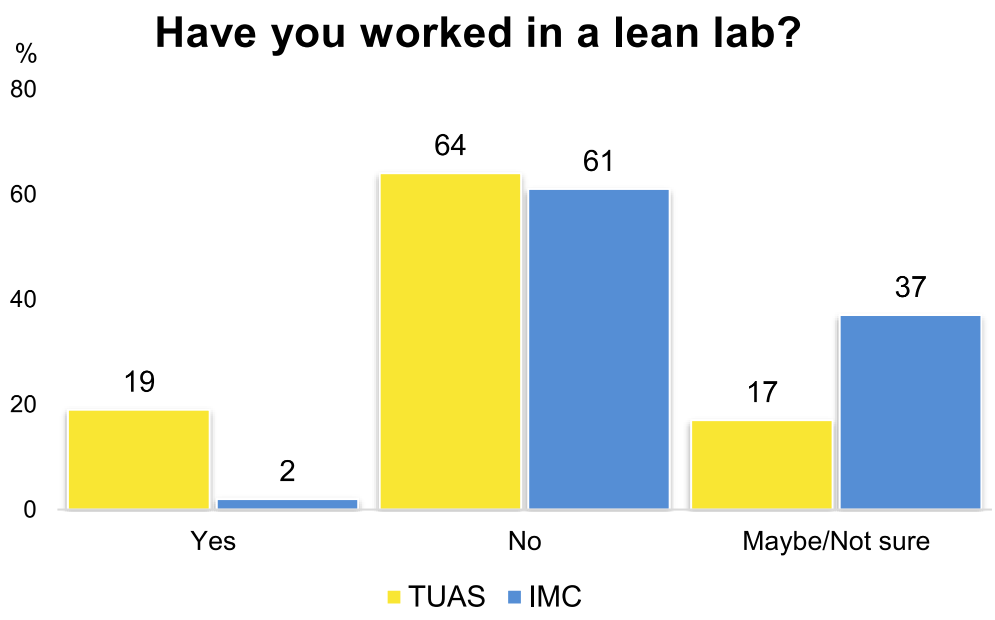
Seen from Figure 9 below, most of the IMC students (84%) have not heard of lean principles before compared to the 91% of TUAS students who have and know what lean principles are.

Figure 9: Answers to the question: "Have you heard of the LEAN-principles before?".



Seen from Figure 10, most students from IMC (61%) reported no experience of working in a lean lab, while 37% were unsure if they have worked in one before. Of TUAS students 64% have not experienced lean in laboratory setting outside of school.

Figure 10: Answers to the question: "Have you worked in a laboratory that had some LEAN-principles implemented?".



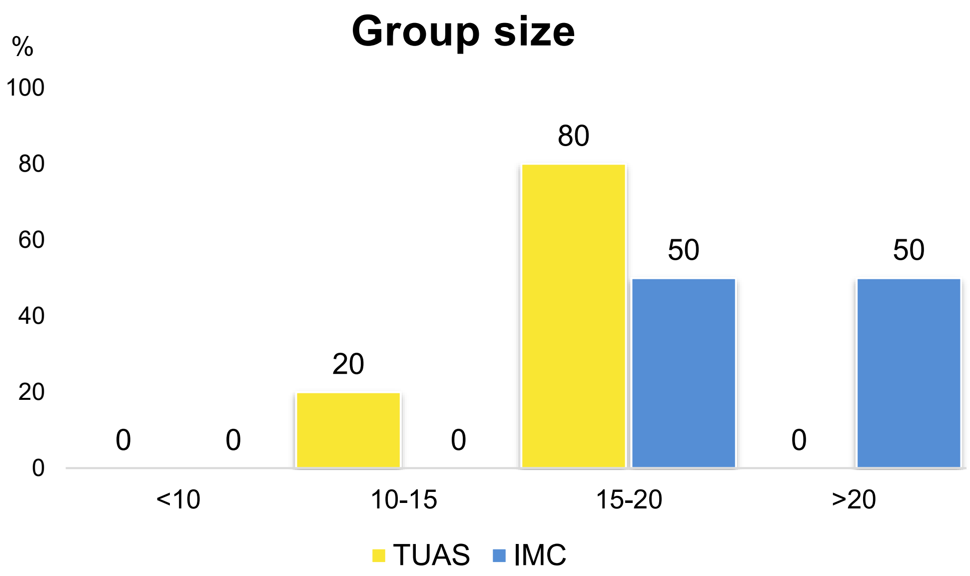
3.2.2 Staff

From TUAS five staff members and from IMC two staff members participated in the survey. The low turnout for staff category participants should be considered when viewing the results presented below.

Student laboratories

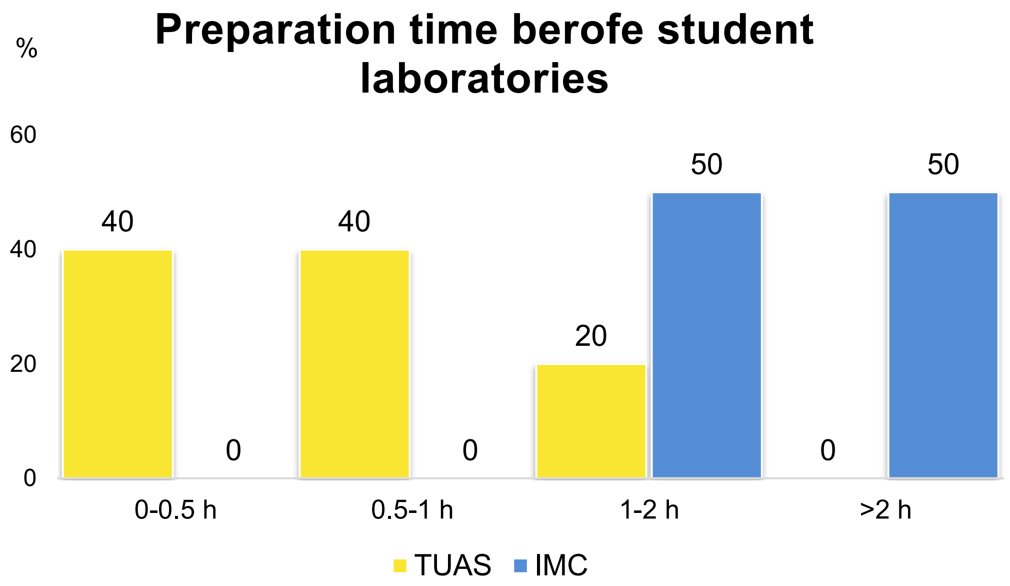
Seen from Figure 11, the majority of TUAS staff said that the group sizes were between 15-20 students per instructor. 20 % said the groups could also be smaller than 15 pupils. In IMC, the results were 50/50 between 15-20 students and over 20 students. Group sizes are similar in both schools, with the difference of one staff member from TUAS leaning more toward smaller group sizes and one IMC staff member leaning more towards over 20 students.

Figure 11: Answers to the question: "How big are the group sizes on average per teacher?".



From Figure 12 below we can observe that IMC’s staff is leaning more towards over 1 hour preparation time for the student laboratories with 50% of the staff answering 1-2h preparation time and 50% answering over 2h preparation time before student laboratories. In comparison 80% of TUAS staff mostly spent under 1h on preparation time before student laboratories with only 20% answering 1-2h preparation time.

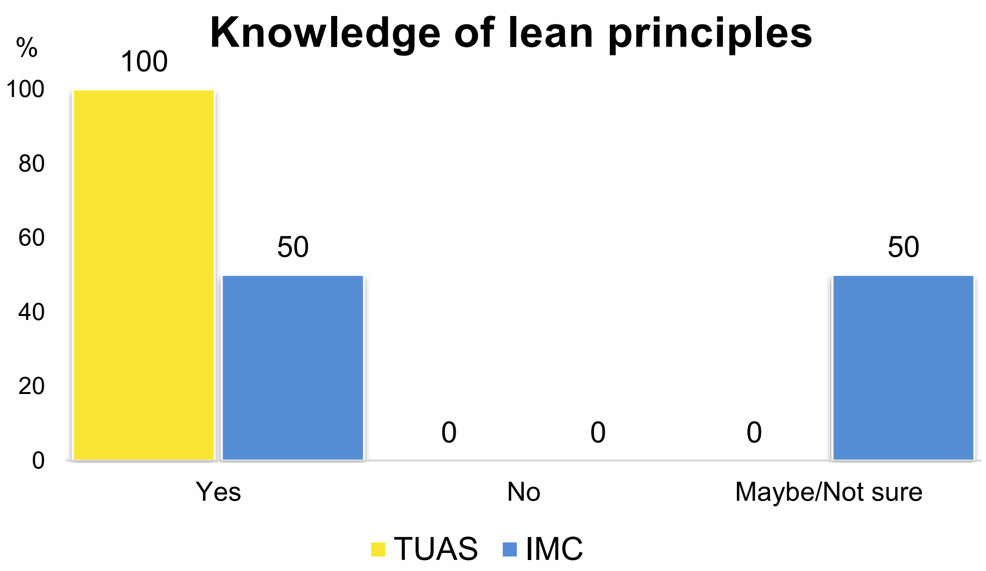
Figure 12: Answers to the question: "Estimate how long does it takes for you to prepare the laboratory for students (put materials out, prepare for the briefing, do slides etc.) before the students come to the laboratory.".



Lean knowledge

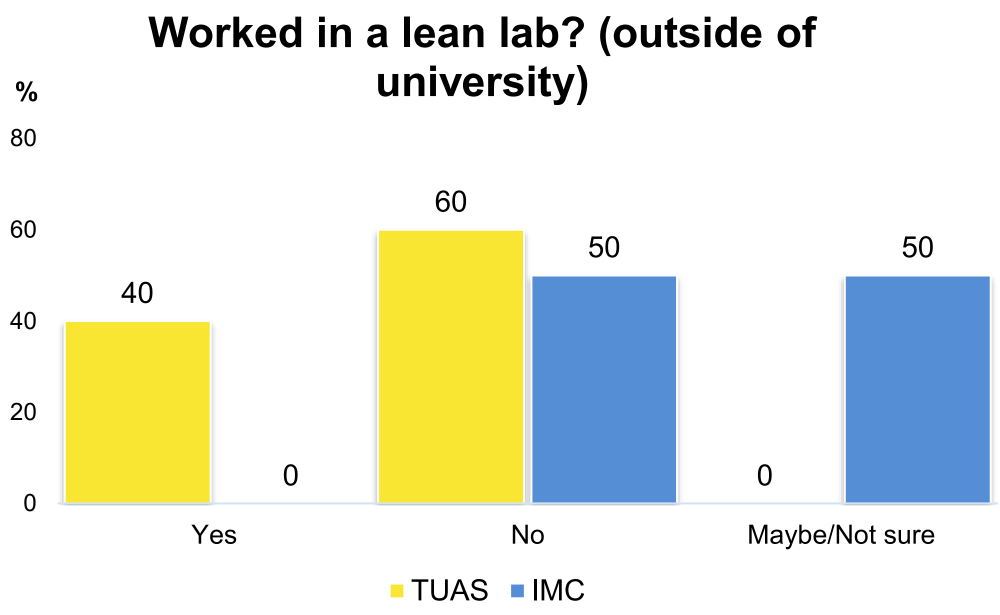
The knowledge of lean philosophy was split in IMC between yes and maybe/not sure 50/50. In TUAS, 100% of the staff knew about lean principles. Answers can be seen from Figure 13 below.

Figure 13: Answers to the question: "Have you heard of the LEAN-principles before?".



TUAS staff survey was differently formulated in the 4th question (Attachment 2) to reflect if the staff has worked in a lean lab outside of TUAS. 60% of TUAS staff have not worked in a lean lab outside of TUAS while 40% of them have worked in one. In IMC 50% answered maybe/no sure and 50% no. These results can be observed from Figure 14. TUAS staff reported in the open question 5 (Attachment 2) that the lean labs they had worked in previously were similar to TUAS laboratories and one staff member commented that lean principles were implemented but just parts of 5S tool without formal labeling.

Figure 14: Answers to the question: "Have you worked in a laboratory that had some LEAN-principles implemented?".



3.3 Conclusions from survey results

The main idea of conducting these surveys was to get the point of view of the people who have worked in TUAS and IMC student laboratories. I wanted to map out the knowledge of LEAN in these circles and the opinions of these groups about the labs' execution. I wanted to get a more objective view of the laboratories to create the best possible implementation suggestions for IMC for the future.

The results comparing the students' answers will have more weight in the evaluation because of the number of answers acquired. When thinking over the implementation suggestions, it is advisable that the needs and opinions of the staff should be further investigated before the implementation plan is set in stone.

3.3.1 Students

Demographics

As seen from Figure 1 the distribution of age of the participants highlights a notable difference between IMC and TUAS that should be considered when evaluating the results. TUAS students were mostly between the ages of 21-30 whereas IMC students were mostly 25 and below and most of the participants being even under 20 years of age. Of TUAS students only 4% were under 20 years of age.

This age gap may be partially explained by the fact that 29% of students from IMC were first year students, whereas no first-year students participated in the questionnaire from TUAS. This can be observed from Figure 2.

This deviation suggests a slight knowledge gap between IMC and TUAS respondents. TUAS participants could possess more advanced understanding or experience of the field of study compared to their IMC counterparts.

Notable is also the difference in study programs between the schools. IMC's Medical- and pharmaceutical Biotechnology -program is focused on a more specific part of biotechnology. In comparison TUAS' program of Biotechnology and Chemical Engineering teaches a wider range of biotechnological fields and the specificity comes on the 3rd or 4th year of study when the student selected their major. This also affects the difference in knowledge of the students who participated in the survey.

Student laboratories

Duration on laboratory sessions and professors initial briefing before the sessions

In question 5 I wanted to get an estimate from the students of the time spent in an average student laboratory lesson. The data did not show significant differences here, which was surprising to me when I compared with my own observations during my exchange year in IMC. Most students from TUAS and IMC estimated the lessons to be around 4-5h. In my experience I would have estimated that the lessons lasted notably longer in IMC because of waiting times compared to TUAS.

However, some differences can be observed when data is looked more closely through the demographics of the students. IMC's data reflects mostly 1st and 2nd year students' responses compared to TUAS' data that is produced mainly by 3rd year and more advanced students. This explains why TUAS students reported longer laboratory sessions as more advanced studies usually have longer and more complex laboratory experiments, but this does not explain why IMC students reported longer lessons in the laboratory. The duration of the sessions in IMC could be linked to the organizational part of the laboratories mentioned by the exchange students in their interviews. The difference in demographics and similarities in answers could also be explained by differences in study fields and types of experiments performed or the academic structure of each field.

The same reasonings could be stated about the results of the question 6 answers about the time estimation of the professor's briefings seen in Figure 4. It is interesting that the academic study year of the students did not bring more deviation to the answers between IMC and TUAS. This would suggest standardized practices in the briefings across both institutions. In my experience the briefings lasted longer in IMC rather than at TUAS and were more detailed because IMC did not have the same expectations of the students' preparedness that TUAS has for the student laboratory lessons.

Similarities between both time estimations are also an interesting contrast to the experiences of the exchange students interviewed. The interviews suggested that there could be a clearer division in the answers to questions 5 and 6. They also suggested that IMC seemed quicker and more streamlined in the laboratory experiments and TUAS laboratory lessons needed more time from the students. The interviews of the exchange students support my observations of the time estimations. Data provided from the surveys seems to demonstrate that this might not be the case. Streamlining the processes and cutting from the practical part of laboratory experiments does not necessarily make the lessons quicker if there are other parts that bring the efficiency down.

Accessibility of support during student laboratories and laboratory organization

Mostly the highlighted areas of this part of the survey are the differences in teaching styles, laboratory environments and students' own familiarity with the laboratory space.

The set of data seen in Figure 5 to the question 7 about getting help and answers during laboratory lessons supports the notion the exchange students made in their interviews of TUAS requiring more self-management and independent working style already in the student laboratories. This is in sharp contrast to IMC's teaching style in the student laboratory, where guidance more often includes demonstrating procedures directly.

When comparing the results from question 8 seen in Figure 6, we also must consider the different teaching styles mentioned by the interviewed exchange students, but in addition the size of the laboratories. In IMC, the answers to asking help to find equipment could be explained by smaller lab space and teachers arranging equipment for the students beforehand. On the other hand, in TUAS extensive lab visualization with labeling and tapings can help students find things even if they reflected not getting that easily physical help from the professors. However, the larger lab area can have the opposite effect if everything is not clear to the students through lean visualization, because TUAS notably expects more autonomy for the students during the experiments.

The results from question 9 seen in Figure 7, suggest that the students from both institutions are familiar with their laboratories at least when it comes to the basic equipment needed for the experiments. TUAS students knew already where the equipment was located, that could be due to the experience gap between the IMC and TUAS participants. Most IMC students could find equipment easily themselves if they already did not know the location, which would suggest the difference caused by a smaller lab space.

There are some highlighted differences in the organization of the labs and teaching styles, but the result is similar from the point of view of the students when it comes to accessibility of help and organization of the laboratories. Notably, the size of the teaching environments affects the results too.

Preparation for student laboratories

The data analysis on this question was a bit more difficult because of all the combinations the students produced. Therefore, it did not make sense to create a similar figure to show the data as in other questions.

Approaches in preparation to the laboratories seem similar in IMC and TUAS, but considering the interviews of the exchange students and my own experience TUAS does enforce stricter standards for note documentation and how to answer pre-assigned questions. In addition, in TUAS if the pre-assigned questions are not done and signed by the instructor before the experiment, the students are not allowed to participate in the experiment. This kind of practice is not done in IMC. The practice is meant to enforce more independent working during the experiment and motivate the students to thoroughly investigate the experiment beforehand and answer pre-assigned questions thoroughly. Notable was that the students of IMC listed in the open-ended answer that they prefer watching videos about the experiments beforehand. This was not that popular in TUAS which could suggest that the pre-assigned questions are formulated in a way that all the important parts of the experiment protocol are highlighted more or that IMC students younger age makes them use more tools in preparation for the experiments.

Lean knowledge and working outside of student laboratories

Working outside of student laboratories

TUAS results for question 10 are especially surprising given that the study program in TUAS includes 3 practical training periods usually done as summer jobs during summer breaks. In TUAS students need to complete all their practical periods to graduate, and they usually last around 2 months. TUAS students are equipped to work in process lines and engineering tasks and the data suggests that most have chosen a different practical training place than a professional laboratory. On the other hand, 26% that have 1-6 months of experience have done their practical training in a laboratory. IMC only includes one practical training period during the 3rd year and since most students who participated in the survey from IMC were 1st and 2nd year students, this explains their limited exposure to other laboratories than student laboratory lessons.

Lean knowledge

Lean philosophy and tools are used globally in various industries beyond laboratories and are notably absent from IMC's curriculum and everyday laboratory practices. Their better inclusion could equip the graduates with valuable skills, giving them a competitive advantage in the job market. This was my experience after applying for a full-time job in a professional laboratory in Austria after my exchange year in IMC. I had more knowledge about industry standards than most applicants for entry level jobs which lead me to land non-entry level job right away after school, rather than being stuck in internships 6-12 months like some of my colleagues from IMC. This cannot be fully credited to my knowledge of lean principles, but it did not hurt my case when applying for jobs.

This lack of lean knowledge but also need for it can be seen from Figure 10, suggesting indirect exposure to LEAN practices potentially in Austrian industry settings. From my personal experience lean principles are widely used in Austria as well and students have come across the philosophy or some of the tools but are not equipped to recognize them. The status of lean knowledge is considered more a responsibility for the company to teach rather than teaching and practicing it already in the university setting.

In Figure 10 it can be observed that most TUAS students have not worked in a lean lab outside of school and these results are linked to the results of TUAS students reporting on not working in a laboratory setting outside of school in Figure 8. Interestingly, multiple IMC students reported not working in a lean laboratory setting before but were listing lean principles in the open question 13 as differences for working in a laboratory outside of school compared to the student laboratory experiments. The lack of lean knowledge in IMC students is evident in all questions of the survey regarding lean.

Open questions

The first open question (question 12) supports the data in Figure 9 and 10. TUAS students listed different tools of lean like 5S, Kaizen and organizational parts of lean as their answers to this question. From IMC's answers to the 11th question only one student could name different principles and tools of lean, and this student reported that he or she worked in a lean lab in TUAS as part of his or her exchange year. One student from IMC also reported that they did not know how these principles could be applied to a laboratory environment.

The second open question (question 13) showed that IMC students who answered lack of knowledge about lean, were listing differences that coincide with lean philosophy and tools as their answers to differences between student laboratories and working in a professional laboratory. Students from IMC listed as examples that working outside of university in a laboratory was more streamlined, testing was strictly linear, instructions where clearer where equipment was located, laboratories were more organized, documentation and reporting were different from university and that everything was labelled. These are part of different lean tools and practices, which support the theory that lean principles are an industry stable also in Austria. It would therefore also benefit the students to learn about the subject already in school and practice some of the tools before graduation. Multiple IMC students in addition listed as a positive difference that they had more autonomy and independence in the laboratories outside of university. One student liked the fact that this independent preparation of equipment and experiments required more critical thinking and another student thought that this kind of flexibility in self-management would improve the deeper understanding of the experiments.

TUAS students commented that working in laboratories outside the university was pretty like working in student laboratories. Some said that there are differences sometimes in the instructions being vaguer and if the professional laboratories do not use lean principles, it is a bit more chaotic.

3.3.2 Staff

Unfortunately, the answers from staff of each institute were not as abundant as with students. The results might not reflect the opinions of the other staff members. At IMC two members of staff participated in the survey and at TUAS five members of staff participated. The questions sent to staff of IMC and TUAS can be seen from Attachment 2.

Student laboratories

Group sizes were mostly the same in IMC and TUAS, which is a good starting point in lean implementation. Group sizes should be kept manageable, and this is already under control in IMC if the answers from the staff reflect on the general view from the staff of the study program.

The results for question 2 about preparation time needed before the students experiments supports the observations of the exchange students about the professors preparing all needed material and equipment ready for the students before the experiments versus TUAS instructors expecting the students to perform the whole experiment with also the practical laboratory parts. The independent working model reduces staff preparation time and improves efficiency without compromising student-perceived time in the lab seen from the student survey Figure 3.

Lean knowledge

Results for question 3 were expected from TUAS staff as they are required to teach and enforce the use in the student laboratories. IMC's one staff answer of maybe/not sure also suggests that lean is indeed an industry standard in Austria, but the teaching of the principles falls on the company rather than the schools. However, it is hard to make more assumptions from the staff's point of view about lean knowledge because of the answer amount.

4 Suggestions

In the next chapters, I will make implementation suggestions for IMC to positively affect the efficiency of the student labs and their experiences. These ideas can be taken as a base for a lean implementation plan to a student laboratory. Over all the data presented in the previous chapter suggests that lean principles and tools could significantly improve operations in the student laboratories in IMC. The suggested ideas are based on the interviews, surveys and observations made during this thesis' writing. Most of the observations were made from the viewpoint of a student. When planning a proper implementation process of the suggested ideas, staff should be more thoroughly interviewed and involved in finding a golden middle road which serves students and staff the best.

The main goal of implementing lean philosophies into student laboratory environment is to support teaching, clarify theory learned in class and to motivate students to dive deeper into the subjects with their understanding. Not all principles or tools of lean are well suited for school laboratories and can be even more confusing to the students rather than helpful. With these suggestions I want to achieve a clear and straightforward biotechnology laboratory design that enhances teaching and learning as effectively as possible. A lean lab is supposed to allow the students and the staff to navigate the laboratory without trouble, help the students to complete their experiments and tasks without unnecessary delays and waiting times, to improve the students understanding in what they are doing and do all this in a clean, organized, and safe working space. (Hachemi 2019.)

To be able to achieve these goals with the implementation it requires a long-term effort from everyone involved, performance monitoring and constant development and innovation to see what the best tools and ways to better IMC’s student laboratories are. Things that work in other student laboratories and spaces might not be exactly right for IMC and that is why there needs to be clear goal in mind when planning the implementation of these tools and principles. (Hachemi 2019.)

4.1 Implementation ideas

Lean 5S

The best and easiest way to start adding lean principles into the student laboratories in IMC is to implement the 5S tool. This is an efficient way to start the process of implementation of lean and it will bring notable differences right away when properly done. Waste reduction will increase efficiency and organization in the labs, and it is an effective way to do inventory of equipment and materials. A clean and organized environment also promotes a safer working environment for the students. Recognizing not only clutter as waste but also certain placements of equipment or actions that are unnecessary will streamline the experiments and establish a better workflow and higher productivity during student laboratories. When visualization of the lab is done properly, students will spend less time looking for things or asking for help from the staff. It also helps students and staff identify issues and helps everyone maintain the organization done in the start of the 5S process.

VSM

VSM is an effective planning tool before starting the 5S method. Mapping out the current situation and thinking through the ideal future look of the laboratory area. VSM can be used also during the 5S process, and it supports a successful execution of the methodology. It can help to see what resources are needed during the process. Visualizing the laboratories' current situation beforehand helps concretize the time the 5S process will take.

Sort

The process needs to start with the identifying and removing of items that are unnecessary or not adding value to the space. Items that are expired or broken should be tossed right away. Only things used in teaching should be kept in the laboratory.

Labelling or more commonly known as red tagging of items can be used in this step to identify what items are used less regularly. In the label should be marked at least what is the item, where it was found and when. A timeline for the sorting phase should be established at the start, and staff should be aware of it and help by removing labels from equipment that is still needed or used during the sorting period. The timeline for this phase should be at least 3 months. Items that still have a red tag or label on them after this period should be tossed.

Set in order

Remaining items are thoughtfully and logically organized with a layout plan, and their places are marked and labelled clearly for everyone to see. The layout plan can be made using software like AutoCAD and the process starts by measuring all the dimensions and marking down unmovable furniture. The main goal is to make it easy to find materials and improve the movement of items in the workspace.

Tools and materials are placed based on their purpose and equipment that are used together should also be placed near each other. The placement of each item should be the most efficient and easily accessible place for it. When organizing items the question “Where is this item most commonly used?” Should be kept in mind. Placement and the need of utilities like water or gas during experiments also affects equipment placement. Placement of everything should go according to lean principles, but also based on ergonomics, safety, and space requirements.

Markings for bigger equipment should be made with blue tape, and everything should also be labelled. Cupboards and shelves should also be labeled to visualize what is inside of them without having to open the doors. This will make it easier for the students to always find what they are looking for.

Shine

Clean the laboratory thoroughly and set in order a cleaning plan that is monitored somehow to upkeep the cleanliness. The cleaning plan and standard of cleanliness should be set as clear instructions for everyone to see. This can be done with laminated pictures of how a desk or laminar flow cabinet should look like after each experiment has ended. Monitoring can be done by designated students after each class or experiment or by a staff member. Designating a monitoring student or student pair for each class will teach the students about lean protocols but also put more responsibility on them and help them become more independent in lab work. The monitors can have a printable list of things that need to be checked after everyone has left the laboratory. This list can include checking that used equipment is in a washing machine, gas tanks or light are off, distilled water tank is filled, ethanol spray bottles are filled among other things. From Picture 10 below you can see an example of a monitoring form used by the students of TUAS.

TURKU AMK

MARK THE TASK AS DONE WITH A CROSS ONLY WHEN IT IS DONE AND IN ORDER.

IF ANY TASK DOES NOT APPLY TO THE PREMISES USED DURING A WORK, AND IT IS THEREFORE NOT PERFORMED, MARK A DRAW.

video

LAB MONITOR'S DUTIES

AT THE START OF A LAB SESSION OR IN THE MORNING:

In principle, the premises should be in order at the start of a new lab session or in the morning; if this is not the case, notify the responsible person.

Done = X

• Create an overview of the day's work including the apparatuses and rooms to be used. The monitor is responsible for all the premises where the group works. Premises in use: ______ ______ ______ ______ ______ ______ ______	
• Empty the dishwasher of dry dishes and put all dishes where they belong, including those on the desks and drying racks in the equipment maintenance room and the laboratories, even pipets and burettes.	
• Check that the scales are clean and clean if needed. Adjust scales and check operation, if needed.	
• Get lab water, if needed.	

AT THE END OF A LAB SESSION OR AT 4 p.m.:

The premises and equipment are to be left tidy for the next user.

• Collect dirty dishes left in the premises or in the equipment maintenance room. Put the dishwasher on and do the manual washing-up, if needed.	
• Remove dry dishes from the dishwasher and off the equipment maintenance room desks and all draining racks, and put them where they belong, including pipets and burettes.	
• Check the glassware in the laboratory cupboards, replenish where needed.	
• Wash pipets and burettes with the washer and lift to dry.	
• Ensure that all cabinets for toxic substances are locked and that the key is in the supervisor's office.	
• Check pH meters (caps, storage solutions).	
• Check that all gas cylinders used by the group are sealed.	
• Switch off and clean equipment (except those marked with a "Work in progress" sign). Also check and, if necessary, clean the scales in the premises used.	
• Check that all fume hoods and laminar flow cabinets are clean and switched off (unless otherwise instructed in the cabinet instructions), and that the sash is down.	
• The full bottles of dangerous waste are taken to the room for dangerous waste under supervision of responsible person.	
• Check that microbial waste, especially GMM, has been autoclaved.	
• All items and equipment are where they belong.	
• Pigeonholes for labels have been filled in all rooms used by the group (labels can be found on the document shelves: the first floor shelf is in the corridor next to the door to lab A125. The second floor shelf is in the corridor opposite to the door to lab A215).	

All checked and found to be in order.

We left the room at (time): _______________

_______________________________ Date and signature (monitor)

_______________________________ Signature (supervisor)

31.8.2016 Jani Pelkonen
29.3.2021 Jarno Pusa and Emilia Suvanto

Picture 2: Monitoring form from TUAS

Standardize

Develop a set of rules and a clear written down guideline that everyone follows. This should clearly state the responsibilities for all who work in the laboratory space. Visual aids and regular training can help the process. The training can be taken as part of the mandatory laboratory safety training everyone must do to work in the lab. As visual aids QR-codes for lists of laboratory standards for cleanliness can be placed outside of the laboratories. QR-codes can be added also to commonly used or all equipment to add videos of how to use and maintain them.

Sustain

This is the most important part of the 5S process. For the implementation to succeed, it must be regularly monitored and effectively communicated to everyone. One-way TUAS has done the monitoring of the rules are weekly lean meetings with the staff and involving students in the auditing process. Various kinds of checklists like the Lab monitor's duties -form can be helpful tools in upkeeping the organization. TUAS has in addition to monitoring duties monthly 5S check duties, where a group of students or staff check the laboratories more thoroughly with a longer and more specific list and notes down any discrepancies. For the students, this is part of a course where lean principles are taught and discussed, and they must do at least one of these monitoring duties to pass the course. It is also important to have some sort of feedback system in place to get into the lean philosophies constant development mindset. When problems arise it is important to recognize why and what needs to be done to improve the situation.

Safety aka. 6th S of lean 5S

While the traditional 5S tool does not prioritize safety as its own step in a school laboratory, the safety of the students should be a priority. Equipment in the lab should have their safety instructions close to the equipment for everyone to read. A straightforward way to do this is taping QR-codes to each device or near them with educational videos of maintenance and use of the device, but also the safety instructions attached. The equipment should have a fixed location in the lab that is marked clearly with blue tapings and hazardous areas like doorways or utility valves should be marked with yellow and black warning tape. The fire safety equipment and first-aid kits placements should be logical and easily accessible. All safety equipment should be clearly marked including emergency showers and eye flushing stations. (Hachemi 2019.)

The placement of the items in the lab should promote ergonomics and reduce unnecessary movement. This enhances the efficiency of students working in the area but also comfort and safety by reducing accidents. For example, tabletop centrifuges and microscopes are placed on workbenches for easier handling and seating should be available for tasks that require more time spent next to the equipment. Stools can be stacked and have a designated area for keeping them when not in use. (Hachemi 2019.)

GDP

In the support of other lean procedures implementing GDP and more independent working during experiments could help the student's self-management skills and to reduce workload from the professor's point of view. Since IMC is more academic in nature compared to TUAS, the extent of the implementation is not beneficial to reach TUAS’ level. GDP, however, is an extremely useful and appropriate skill that needs practice. It would be beneficial to implement it in all the laboratory experiments. It is one thing to read about it in theory versus learn by doing. Promoting GDP also helps the students in the making of the reports after the experiment more accurately and to understand on a deeper level what were the important parts of the experiment.

One way to take GDP in use could be implementing physical laboratory diaries for each student. Notes and pre-assigned questions about the experiment would always be marked in the diary and laptops or other devices would not be allowed in the laboratory. This would also help save space. Another possibility would be to do this on a computer in a notebook application. The important part is that the pages written during the experiment would be quickly checked by the instructor before the student can leave the laboratory for the day. With a physical laboratory journal, the instructor can sign the pages before the student leaves. Students would have to mark down things significant to the reproducibility of the experiment like, operator(s), date, materials used and their expiration date and lot numbers, equipment used and anything that deviates in the experiment from the protocol.

Kaizen

Kaizen method could also be a useful tool to improve the feedback loop of 5S sustain step. IMC students already have ways to give feedback on each course and therefore using that feedback for the bettering of the laboratories with lean would not be such a huge change. Specific end of the course feedback surveys focusing on observations, comments, and suggestions of the students on the improvement of the experiments or placement of items during the student laboratories could be valuable information on the viewpoint of kaizen method. Professors could incorporate a template survey that could be modified for specific experiments to their courses and inform students about it before the laboratories. Innovative and active student feedback could positively affect their grades from the experiments. This would motivate students to pay attention to what works and what needs improvement while they are doing the experiments. The Kaizen approach is also inherent part of other lean tools like 5S that aim for continuous improvement. (Hachemi 2019.)

Kanban

Kanban board is a great way for the staff of the laboratories to communicate with each other about the upkeep of 5S or the status of materials etc. This lean tool is more for the staff that work in the laboratories every day rather than the students but still help to keep the maintenance of the laboratories up to date. In its most simple form Kanban board can be a white board with sections like “up next”, “in progress” and “done”. Ordering of materials, equipment maintenance or 5S checkups could be examples of tasks that would go on a Kanban board. It can be customized based on the daily or weekly operations of the staff. The visuality of the board streamlines and clarifies communications between the staff. (Hachemi 2019.)

4.2 Resources

The plan of execution can be made based on this thesis and would be a good topic for someone to continue from. The actual process of implementation would need a bigger group or a task force to be done. It would be best if most of the parts were done during a summer holiday to cut the interference it can cause to the students during a semester to the minimum. A structured timeline for the sorting, organizing, and cleaning of the laboratories would be a long-time commitment that could potentially last anywhere from 3 to 6 months. It would need involvement of the staff and a thesis student or two. Implementation should be done as project-oriented execution with a project manager.

Lean 5S implementation would require resources also in training staff and students on the principles and correct working practices. A working lean 5S tool can lower operational cost when less time is spent on searching for items. Also, safe laboratory minimizes accidents that can lead to potential medical costs. Additionally, reducing waste and streamlining the processes can lower operational costs and continuous improvement and auditing can significantly reduce material waste and inventory costs.

VSM requires time and effort in the planning stage and software to use. Good planning of the implementations can allow for the laboratory space to access its potential more efficiently and identifying resources helps to determine what is already available and what is necessary for the laboratory. This will prevent over-purchasing and help to go through the inventory.

Most of the implementation suggestions require a lot of time and resources in staff or student engagement. Although at the start the process requires investments the long-term benefits outweigh the initial costs. It is a long-term commitment and will require a lot of planning to be executed properly and to have long-lasting effects.

5 Summary

This thesis presents a comprehensive comparison of student laboratory experiences across two dual degree agreement institutes, IMC and TUAS. The focus of the analysis has been the differences through the lens of lean philosophy and tools. The main gain of this analysis was to help IMC to get ideas to efficiently enhance their student laboratories with lean practices.

The research is based on the surveys conducted to the students and staff of both schools and the observations of exchange students who have experienced both educational environments. The findings of this study indicate notable differences in teaching styles, laboratory settings and documentation practices. The interviews of the exchange students and surveys conducted regarding this thesis gave much information to justify the suggestions made for IMC. The surveys successfully identified key differences, but some questions, such as those assessing lean knowledge, could be expanded to assess the depth of understanding or to be formulated in a way that knowing the word lean would have not been necessary, but rather just the practices. Additionally, including a comparative self-evaluation of the students' preparation or follow-up activities could have yielded richer data. I would conclude that a survey format might not have been the best way to collect this data. The surveys had their pitfalls and could have been formulated differently to be able to get more out of them. Most of the answers, especially from IMC students, reflected the fact that the school laboratories had been the only laboratories they had worked in. Survey answers between the schools' students did not have as much difference as I had hypothesized and thought based on the interview of the exchange students. In addition, unfortunately I could not get enough answers from the staff from either of the schools to make clear assumptions from. A greater participation rate from staff would have offered more balanced conclusions and insights needed to make assumptions from their point of view. If the surveys were conducted again, I would need more time to collect and contact the staff better. Getting answered via email did not pan out in this case.

A better way to collect more in-depth data from the students could have been through focus groups and interviews or discussion sessions with them. In addition, adding direct observation sessions of the student laboratories or an experimental trial of Lean implementations could have provided empirical evidence to support the suggestions. For example, testing the 5S tool in an IMC lab for a semester and measuring its effects on efficiency and student satisfaction would provide actionable results. This could be a topic for someone else to continue if more data is required from IMC's side to justify the suggested changes.

Reflecting on the data provided, it was suggested that IMC could implement, for example lean 5S tool with VSM and added importance to safety of the students in addition to Kaiyen and Kanban methodology. Also, adding GDP into the student laboratories could be a valuable skill to practice for the students. The adoption of Lean principles, such as enhanced organization via 5S or GDP, would significantly improve student learning by fostering a more structured and independent approach that TUAS enforces. I think this would better equip the students of IMC for professional environments where these practices are an industry standard. Additionally, integrating lean principles would streamline workflows for IMC staff, reducing prep times and allowing them to focus on pedagogical improvements rather than logistical or practical tasks of the student laboratories.

Both my experiences and those of exchange students underscore the importance of student autonomy, as seen practiced more at TUAS. Adapting TUAS's approach to IMC would allow students to develop critical skills like resource management and documentation that enforce students' development to professionals already during school years. These observations also highlight the importance of balancing academic rigor with practical skill-building to better prepare students for industry demands. The answers from the IMC students to the open-ended question of the differences in working in a student laboratory compared to a professional laboratory supports these observations and emphasizes the students' needs to be prepared for the industry after graduation.

The implementation of lean principles to their full potential would take time and resources in the start, but the value adding aspects of them outweigh the negative impact. With the implementation of the suggested tools and practices IMC can gain efficiency in their laboratories and graduated students will have a competitive edge in the job market with added self-management and GDP skills in addition to lean knowledge.

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Student Laboratory Experience – Bachelor’s Thesis survey for students

Below are the surveys conducted by me for IMC’s and TUAS’ students regarding their experiences in student laboratories in their respected schools. Surveys were conducted via Microsoft Forms and sent to students by email. First is the English version of the survey sent to IMC’s students and below that is the Finnish version sent to the students in TUAS.

Student Laboratory Experience
- *Bachelor's Thesis survey for students*

The intention of this survey, is to research the differences between student laboratory classes at IMC and TUAS, my home University. The aim is to understand better the most efficient and resource-conscious way to conduct laboratory classes in a University environment. The survey has three sections and takes **a maximum of 10 minutes** to complete.

ɛequired

Data Handling Information

Thank you for participating in the survey. Participation in the study is considered consent to the research use of the information requested in the survey. Participation is voluntary.

Please read the following information about how your data will be handled:

1. *Data Collection and Storage:*

The data collected from this survey will be securely stored on Microsoft OneDrive, a cloud service provided by the Turku University of Applied Sciences. This ensures that the data is protected by advanced security measures.

2. *Access to Data:*

Only I, the principal researcher, will have access to the survey data. No other individuals or third parties will be granted access to the raw data and information collected in this survey.

3. *Data Security:*

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5. *Privacy Assurance:*

Participants' privacy is of utmost importance. All responses are anonymous, and no personally identifiable information, except for age, is collected

1. Information

1. Age *

- ◯ 18-20
- ◯ 21-25
- ◯ 25-30
- ◯ 30+

2. Study year *

- ◯ 1st year
- ◯ 2nd year
- ◯ 3rd year
- ◯ 3+ years

3. How much do you have working experience in a laboratory? (school laboratories excluded) *

- ◯ None
- ◯ 1-6 months
- ◯ 1 year
- ◯ 1-2 years
- ◯ 2+ years

2. Student laboratory experience

This sections questions will focus on your experience in IMC student laboratories.

4. What do you usually do to prepare for laboratory experiments at IMC? *

- [ ] Nothing
- [ ] Read through the protocol beforehand
- [ ] Answer pre-assigned questions set by the professor
- [ ] Make notes to the protocol/workflow/own notebook about the experiment
- [ ] Other

5. How long does an average student laboratory lesson last? (an estimate) *

- ○ 1-2h
- ○ 2-3h
- ○ 3-4h
- ○ 4-5h
- ○ 5+ h

6. Estimate how long does it usually take that you can start your experiment and the professors briefing is over. *

- ○ Under 30 minutes
- ○ 0.5-1h
- ○ 1-2h
- ○ 2+ h

7. How easily can you ask the teacher for help or a question during the experiment? *

- ◯ Quickly and easily, getting help or an answer right away
- ◯ Easily for an answer to a question, but have to wait if I need help
- ◯ Have to wait for an answer or help for a while
- ◯ Other

8. How often do you have to ask the professor, where needed equipment for the experiment are located? *

- ◯ Never
- ◯ Rarely
- ◯ Intermediate
- ◯ Often
- ◯ Always

9. How well do you know where everything in the laboratory/laboratory building is (tools, reagents, machines etc.)? *

- ◯ I usually need to ask the staff
- ◯ If I don't know, I can easily find it myself
- ◯ I usually know where everything is
- ◯ Other

3. LEAN and working outside University

This section is focused specifically on LEAN-principle and working outside school laboratories.

10. Have you hear of the LEAN-principles before? *

- ◯ Yes
- ◯ No
- ◯ Maybe/Not sure

11. Have you worked in a laboratory that had some LEAN-principles implemented? *

- ◯ Yes
- ◯ No
- ◯ Maybe/Not sure

12. If you answered "yes" or "maybe" to the previous question, please, explain in your own words which LEAN-principles you have seen implemented in laboratories outside the University.

13. How has working in a laboratory outside of school differed from working in a school laboratory environment?
You can move to next question, if you have only worked in a student laboratory before.

14. Comments:

Laboratorio työskentely Ammattikorkeakoulussa
- *Opinnäytetyökysely opiskelijoille*

Kyselyn tarkoituksena on tutkia kaksoistutkintokoulujen välisiä eroja laboratorio-opetuksessa. Tavoitteena on löytää tehokkain ja resurssiystävällisin tapa opetuslaboratorioiden järjestämiselle kouluympäristössä. Kyselyssä on kolme osaa ja sen täyttäminen kestää enintään **10 minuuttia**.

* Required

Tietojenkäsittely

Kyselyyn osallistuminen on vapaaehtoista. Osallistuminen katsotaan suostumukseksi käyttää kyselystä saatua informaatiota tutkimuksessa opinnäytetyötä varten.

Lue seuraavat tiedot siitä, kuinka tietojasi käsitellään:

Tietojen kerääminen ja säilytys:
Tästä kyselystä kerätyt tiedot tallennetaan turvallisesti Turun ammattikorkeakoulun pilvipalveluun, Microsoft OneDriveen. Tämä varmistaa, että tiedot suojataan edistyneillä pilvipalvelun tarjoamilla turvatoimilla.

Pääsy tietoihin:
Vain minä, pääasiallinen tutkija, pääsen käsiksi kyselytietoihin. Muita henkilöitä tai kolmansia osapuolia ei päästetä käsiksi kyselyssä kerättyyn käsittelemättömään informaatioon.

Tietoturva:
Tiedot salataan sekä siirron aikana että levossa luottamuksellisuuden ja eheyden varmistamiseksi. OneDriven turvallisuusominaisuuksiin kuuluu edistynyt uhkien torjunta, monivaiheinen todennus ja GDPR-standardien noudattaminen.

Tietojen säilytys:
Kyselystä kerättyä informaatiota säilytetään yhden vuoden ajan keräyspäivästä alkaen. Tämän ajan jälkeen kaikki tiedot poistetaan pysyvästi tallennusjärjestelmistä.

Tietosuojan varmistaminen:
Osallistujien yksityisyys on äärimmäisen tärkeää. Kaikki vastaukset ovat anonyymejä, eikä henkilötietoja, ikää lukuunottamatta, kerätä.

1. Taustatiedot

1. Ikä *

- ◯ 18-20
- ◯ 21-25
- ◯ 25-30
- ◯ 30+

2. Opiskeluvuosi *

- ◯ 1st year
- ◯ 2nd year
- ◯ 3rd year
- ◯ 3+ years

3. Paljonko sinulla on kokemusta opiskelijalaboratorioiden ulkopuolisesta laboratorio työskentelystä? *

- ◯ Ei yhtäään
- ◯ 1-6 kk
- ◯ 1 v.
- ◯ 1-2 v.
- ◯ 2+ v.

2. Opiskelijalaboratoriot

Tämä osio keskittyy kokemuksiisi Turun Ammattikorkeakoulun opiskelijalaboratorioista.

4. Miten yleensä valmistaudut Turun Ammattikorkeakoulun laboratoriotunteihin? *

- ☐ En mitenkään
- ☐ Luen laboratorioprotokollan / -ohjeistuksen etukäteen
- ☐ Vastaan opettajan asettamiin ennakkokysymyksiin
- ☐ Teen muistiinpanoja protokollaan / ohjeisiin / muistivihkoon
- ☐ Other

5. Arvioi, kuinka kauan laboratorio tunnit normaalisti kestävät (per kerta/päivä). *

- ◯ 1-2h
- ◯ 2-3h
- ◯ 3-4h
- ◯ 4-5h
- ◯ 5+ h

6. Arvioi, kuinka kauan opettajan ohjeistus tuntia varten kestää ennen kuin voit aloittaa itsenäisen työskentelyn laboratoriossa. *

- ◯ 30 min tai alle
- ◯ 0.5-1h
- ◯ 1-2h
- ◯ 2+ h

7. Kuinka helposti saat apua tai vastauksen kysymykseesi opettajalta laboratoriotunnin aikana? *

- ◯ Saan vastauksen ja apua nopeasti ja helposti
- ◯ Saan vastauksen kysymykseen helposti, mutta joudun odottamaan, jos tarvitsen apua.
- ◯ Joudun odottamaan vastausta ja apua jonkin aikaa.
- ◯ Other

8. Kuinka usein joudut kysymään opettajalta, missä laboratoriokokeeseen tarvittavat laitteet tai varusteet sijaitsevat? *

- ◯ En koskaan
- ◯ Harvoin
- ◯ Jotakin näiden väliltä
- ◯ Usein
- ◯ Aina

9. Kuinka hyvin arvioit tuntevasi opetuslaboratorioiden välineiden sijainnin? (laitteet, reagenssit, astiat yms.) *

- ◯ Joudun yleensä kysymään muilta
- ◯ Jos en tiedä, löydän itse helposti
- ◯ Tiedän yleensä mistä kaikki löytyy
- ◯ Other

3. LEAN ja työskentely Turun Ammattikorkeakoulun laboratorioiden ulkopuolella

Tämä osio keskittyy LEAN-periaatteisiin ja työskentelyyn Turun ammattikorkeakoulun laboratorioiden ulkopuolella.

10. Oletko kuullut LEAn-periaatteista? *

- ◯ Kyllä
- ◯ En
- ◯ Ehkä/En ole varma

11. Oletko työskennellyt laboratoriossa koulun ulkopuolella, jossa on implementoitu joitakin LEAN-periaatteita? *

- ◯ Kyllä
- ◯ En
- ◯ Ehkä/En ole varma

12. Jos vastasit edelliseen kysymykseen kyllä tai ehkä, kerro omin sanoin, mitä LEAN-periaatteita olet nähnyt työelämässä käytettävän.

13. Kuinka työskentely laboratoriossa koulun ulkopuolella eroaa työskentelystä Turun Ammattikorkeakoulussa?

Voit siirtyä seuraavaan kysymykseen, jos olet työskennellyt vain opiskelijalaboratorioissa.

14. Kommentit:

Student Laboratory Experience – Bachelor's Thesis survey for staff

Below are the surveys conducted by me for IMC's and TUAS' staff regarding their teaching experiences in student laboratories in their respected schools. Surveys were conducted via Microsoft Forms and sent to staff by email. First is the English version of the survey sent to IMC's staff and below that is the Finnish version sent to the staff in TUAS.

Student Laboratory Experience
- *Bachelor's Thesis survey for staff*

I am a student in IMC doing my thesis for the Medical and Pharmaceutical Biotechnology dual degree program. The intention of this survey, is to research the differences between student laboratory classes at IMC and TUAS, my home University. The aim is to understand better the most efficient and resource-conscious way to conduct laboratory classes in a University environment. The survey takes **a maximum of 10 minutes** to complete.

Required

Data Handling Information

Thank you for participating in the survey. Participation in the study is considered consent to the research use of the information requested in the survey. Participation is voluntary.

Please read the following information about how your data will be handled:

1. *Data Collection and Storage:*
The data collected from this survey will be securely stored on Microsoft OneDrive, a cloud service provided by the Turku University of Applied Sciences. This ensures that the data is protected by advanced security measures.

2. *Access to Data:*
Only I, the principal researcher, will have access to the survey data. No other individuals or third parties will be granted access to the raw data and information collected in this survey.

3. *Data Security:*
The data will be encrypted both in transit and at rest to ensure its confidentiality and integrity. OneDrive's security features include advanced threat protection, multi-factor authentication, and compliance with GDPR standards.

4. *Data Retention:*
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5. *Privacy Assurance:*
Participants' privacy is of utmost importance. All responses are anonymous, and no personally identifiable information, except for age, is collected

1. How big are the group sizes on average per teacher? *

◯ Under 10 students

◯ 10-15 students

◯ 15-20 students

◯ Over 20 students

2. Estimate how long does it take for you to prepare the laboratory for students (put materials out, prepare for the briefing, do slides etc.) before the students come to the laboratory. *

- ◯ 30 minutes or under
- ◯ 0.5-1 h
- ◯ 1-2 h
- ◯ Over 2 h

3. Have you heard of the LEAN-principles before? *

- ◯ Yes
- ◯ No
- ◯ Maybe/not sure

4. Have you worked in a laboratory that had some LEAN-principles implemented? *

- ◯ Yes
- ◯ No
- ◯ Maybe/Not sure

5. If you answered "yes" or "maybe" to the previous question, please, explain in your own words which LEAN-principles you have seen implemented and how did it differ from laboratories at the university where you are currently employed?

You can skip this question if you answered nor or not sure to last question

6. Comments:

Laboratoriotyöskentely ammattikorkeakoulussa - *Opinnäytetyökysely* henkilökunnalle

Olen Turun Ammattikorkeakoulun opiskelija, Bio- ja kemiantekniikan linjalla ja teen tällä hetkellä opinnäytetyötäni kaksoistutkintoani varten. Tämän kyselyn tarkoituksena on tutkia kaksoistutkintokoulujen välisiä eroja laboratorio-opetuksessa. Tavoitteena on löytää tehokkain ja resurssiystävällisin tapa opetuslaboratorioiden järjestämiselle kouluympäristössä. Kyselyssä on kolme osaa ja sen täyttäminen kestää enintään **10 minuuttia**.

ɩequired

Tietojenkäsittely

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Tietosuojan varmistaminen:
Osallistujien yksityisyys on äärimmäisen tärkeää. Kaikki vastaukset ovat anonyymejä, eikä henkilötietoja, ikää lukuun ottamatta, kerätä.

1. Arvioi laboratorioiden keskimääräinen ryhmäkoko per opettaja. *

◯ Alle 10 opiskelijaa

◯ 10-15 opiskelijaa

◯ 15-20 opiskelijaa

◯ Yli 20 opiskelijaa

2. Arvioi kuinka kauan kestää laboratorion valmisteleminen opiskelijoille ennen kuin opiskelijat saapuvat laboratorioon tuntia varten. *

- ◯ 30 min tai alle
- ◯ 0.5-1 h
- ◯ 1-2 h
- ◯ Yli 2 h

3. Oletko kuullut LEAn-periaatteista? *

- ◯ Kyllä
- ◯ En
- ◯ Ehkä/En ole varma

4. Oletko työskennellyt laboratoriossa koulun ulkopuolella, jossa on implementoitu joitakin LEAN-periaatteita? *

- ◯ Kyllä
- ◯ En
- ◯ Ehkä/En ole varma

5. Jos vastasit edelliseen kysymykseen kyllä tai ehkä, kerro omin sanoin, mitä LEAN-periaatteita olet nähnyt työelämässä käytettävän laboratorioympäristössä.

6. Kommentit: