Examining the Importance of Understanding During Training: An Industrial Perspective

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Human error is an inevitable existence in virtually all tasks in which an issue arises as humans are almost always directly or indirectly involved with the process. Researchers have examined many past accidents and catastrophic events for the types of human error involved and found inadequate training, deviation from procedures and insufficient knowledge, especially in critical and emergency situations, to be among the most common root causes of these incidents. However, within the field of research aiming to resolve the issue of lack of operator knowledge, researchers have yet to perform studies regarding how to equip operators with this knowledge and the extent to which providing training on important knowledge and concepts can help improve their process operation and prevent human error. The objective of this research is to examine the impact of improving operators' understanding on the following 4 aspects of their process operation: 1) performance, 2) adherence to instructions, 3) emergency response, and 4) retention of learned knowledge and skills. In particular, this study focuses on the use of training manuals as a method of improving operators' understanding. An experiment was conducted where participants were trained to operate a hydraulic pump system using either an explanatory training manual, which describes both 'what' needs to be done and 'why' it needs to be done, or a procedural training manual, which only describes 'what' needs to be done. Participants were then asked to manipulate process variables to achieve production requirements while meeting operating criteria in scenarios that exemplify both real-world normal operation and emergency situations. The results of this experiment indicate that type of manual and educational background showed no significant effect on participants' operation time and accuracy performance of control operations or on the appropriateness of their response to an emergency scenario. However, type of manual was found to have a significant effect on procedural adherence, where participants using an explanatory manual showed greater adherence to procedures compared to those using a procedural manual, though these findings were not replicated for adherence to wait times. All participants also significantly increased in understanding of the process after participating in the training session, with similar levels of knowledge retained after approximately 2 weeks and chemical engineering participants outscoring those from other faculties overall on the questionnaires. These findings identified the usefulness of incorporating explanatory information within a training manual and the aspects of process operation in which an increase in operator understanding was shown to improve. It provided evidence on the importance of operator training and understanding of vital concepts and its impact across the production process, as well as provided insight into the development of better and more appropriate training programs.

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Chapter 1
Introduction

1.1 Overview

Human error is a major cause of accidents in many industries as humans are almost always directly or indirectly involved with all aspects of a process. Case studies and accident investigations have found insufficient training and lack of technical expertise to be common root causes of human error that are partially attributed to various accidents or catastrophes. Due to issues involving time and cost, many companies fail to place sufficient importance on training even though it is an essential factor of operator proficiency. Specifically, training manuals and training programs are often designed to only tell operators what they need to do in a step-by-step procedure, but fail to inform them why they need to do it and its impact on the overall process. This failure results in employees often following procedures blindly without knowing why, which may cause problems especially during emergency situations where they are unable to determine the problem or respond appropriately to resolve the emergency. An appropriate action to execute during a normal situation may be inappropriate during an emergency situation. Similarly, when employees decide to develop their own methodologies because they think it is simpler and better than following the procedures in the manual, it is essential that they refer back to the theoretical concepts underlying process operation before determining the appropriateness of altering the procedural steps. This research study examines written training manuals as printed materials are very commonly used even in modern society. Regardless of the many other formats of presenting training materials, companies generally also have a printed copy of the instructions for operators to follow.

There are many benefits of this research as it is the first within its field to examine the importance of understanding on process operation. The results of this study will highlight the essentiality of adequate employee training and contribute towards the development of better and more suitable training manuals and training programs. It will also enable researchers to perceive the importance of this research topic and inspire them to continue conducting further research on the industrial impacts of understanding. However, a current limitation is the lack of research studies conducted within this research area, especially those that highlight its industrial benefits and influence industries to improve their training programs. Thus, a lot of experimental materials were designed based on a mixture of industrial training programs and university chemical engineering laboratory experiments.

1.2 Objectives

This thesis examines whether the incorporation of explanatory information into training manuals would better equip operators to respond appropriately during process operation in both normal and emergency situations. Explanatory information refers to explanations of the underlying concepts relevant to the process and reasons why certain procedures and sequences must be performed as indicated in the manual. The results presented in this thesis could aid companies in understanding the importance of operator training and its impact across the production process, as well as provide insight into the development of better and more appropriate training programs. Although it is known that lack of operator knowledge is common root cause of human error in many accidents and catastrophes, within this field of research, researchers have yet to perform studies regarding how to equip operators with this knowledge and whether providing operators with training on important knowledge and concepts can reduce human error and aid them during process operation, as well as the extent to which this is true. Thus, the objective of this thesis is to determine whether improving operators' understanding of why they need to implement a certain task, as presented in the form of a training manual, will affect the following 4 aspects of their process operation: 1) performance, 2) adherence to instructions, 3) emergency response, and 4) retention of learned knowledge and skills.

1.3 Research Approach

The focus of investigation in this thesis is to examine a novel operator's usage of a training manual and their degree of understanding about important subject matters, as well as the impact of their understanding on improving process operation. The approach taken in this thesis is to conduct an experiment that exemplifies a real-world process operation during which several normal operation trials will occur, followed by an emergency scenario. Participants will take on the role of a novel operator and will be randomly assigned either an *explanatory training manual*, which describes both 'what' needs to be done and 'why' it needs to be done, or a *procedural training manual*, which only describes 'what' needs to be done. Under the condition that their only source of external aid during operation is from the assigned training manual, participants will manipulate process controls in accordance to the instructions listed in the manual and/or their personal judgements in order to uphold operating criteria. For this experiment, four critical aspects were used to assess participants' proficiency during operation of a simulated industrial process: 1) performance in terms of operation speed and accuracy, 2) adherence to the procedures listed in the training manual, 3) ability to respond appropriately and accurately under limited guidance during an emergency situation, and 4) amount of learned knowledge and skills retained after a 2-week period. The results of this experiment will identify the usefulness of incorporating explanatory information within a training manual and the aspects of process operation in which an increase in operator understanding is shown to improve.

1.4 Structure of Thesis

This thesis is structured in the following format:

Chapter 1: Introduction contains the overview, objectives, research approach, and structure of this thesis.

Chapter 2: Background Information contains a detailed literature review of relevant research studies conducted on the topics of human error, employee training, and effect of understanding on process operation.

Chapter 3: Experiment describes the design of the research experiment performed by participants, as well as the methodology used to conduct and analyse the results of this research study.

Chapter 4: Results presents the statistical results of this experiment, highlighting the effect of understanding on the 4 factors of performance, adherence, emergency response, and knowledge and retention.

Chapter 5: Discussion describes the significance of the research findings obtained from this study and their implications to both the research field and society. It also lists the limitations of this research experiment and suggests ways it could be improved for future studies.

Chapter 6: Conclusion summarizes the main findings of this thesis and proposes a research direction that warrants further investigation for future work within this same area of study.

Chapter 2
Background Information

Human error is a field of research that demands much attention due to its existence in virtually all tasks and processes in which an issue arises. Chapter 2 describes a few of the more relevant case studies and experiments performed by other researchers on the topic of human error prevention, with a focus on employee training and the usage of training manuals. This literature review is comprised of two main bodies of publications: sections 2.1 to 2.3 which examines research on human error and sections 2.4 to 2.7 which examines research on employee training. This chapter introduces the topic of human error, describes the importance of reducing human error, examines the impact of employee training as a preventative measure against human error, and finally concludes with considering the effect of understanding on influencing operators' control of a process operation.

2.1 Human Error

Human factors is a field of study that examines the impact of human behaviour and interaction with system elements. It involves the application of scientific principles to optimize the design of the work domain, equipment and procedural operation such that they compensate for the limitations and are compatible with the needs of workers so to facilitate human well-being and more effective and efficient performance [1]. However, as a result of the limitations in humans' physical capabilities and mental capacity, humans often unintentionally deviate from the desired outcome or make a mistake while aiming to achieve process demands [1, 2]. Human error has been found to be an inevitable existence in virtually all tasks in which an issue arises as humans are almost always directly or indirectly involved with the process, whether it be physically making a mistake or a lack of foresight when creating the system which resulted in the mishap.

Human error has been identified as one of the most common causal factors behind a large majority of accidents and catastrophes within the industrial sector [1]. Specifically within the chemical process industry, research studies performed throughout different time periods consistently reported human error as a predominant contributor to accidents resulting in substantial financial losses, namely from property damage [2]. With the adverse effect of human error on significantly reducing production performance, quality and profitability, industries have become increasingly aware of the growing need to develop and implement human error reduction practices to prevent or eliminate these errors [2, 3]. However, it is important that companies do not purely attribute human error, wherein the error is simply viewed as an accidental mistake caused by the worker, as the root cause of a deviation. Rather, companies should investigate further into the incident to examine the factors that caused the human error to determine the true underlying root cause and ways the process could be improved to mitigate the deviation [4].

2.1.1 Review of Industrial Accidents and Catastrophic Events

The U.S. Chemical Safety and Hazard Investigation Board (CSB) is an independent and non-regulatory federal agency headquartered in Washington, DC, United States that conducts root cause investigations of industrial chemical accidents. CSB also makes recommendations to production plants and regulatory agencies to improve worker safety and the effectiveness of protocols and regulatory enforcement. Many industries have implemented these recommendations under the supervision of CSB staff and have seen in a positive improvement in creating a safer work environment [5].

The following subsections briefly describe 3 major industrial accidents investigated by CSB that occurred in recent U.S. history and highlights a few of their root causes that originated from human error. This list is by no means exhaustive and there are many other accidents and catastrophes that have occurred due to some type of human error being the root cause.

2.1.1.1 BP Texas City Refinery Explosion and Fire

On March 23, 2005, an explosion and fire occurred at the BP Texas City Refinery during start-up of an isomerization unit after maintenance. Operators continuously pumped flammable liquid hydrocarbons into the raffinate splitter tower of the unit for over 3 hours with no output, which was contrary to start-up procedures. Regrettably, the control instrumentation erred and displayed false readings, while the critical high-level alarms failed to activate and alert operators that the tower was overflowing into the overhead pipe. Pressure rapidly rose as liquid filled the pipe, opening the pressure release valves and discharging the liquid into a blowdown drum. This drum also became overfilled and then erupted with a geyser-like release of volatile liquid from the vent stack, which was ignited by an idle diesel truck parked 25 feet away, forming a flammable vapour cloud. As the 3rd largest oil refinery in the U.S., this incident was recorded as one of the worst industrial catastrophes in recent history with 15 people dead and another 180 injured, a shelter-in-place order requiring 43 thousand residents to stay indoors, structural damage up to ¾ mile from the refinery, and financial losses of over $1.5 billion [6].

As identified by CSB, this catastrophe was partially attributed to the human error-related root causes of supervisory oversight and insufficient training. Due to supervisory oversight, there was a lack of technically trained workers present during the start-up, which violated BP's safety guidelines as it was considered an especially hazard time. They also failed to assign an additional board operator as recommended in a staffing assessment for all isomerization unit start-ups [6]. Concerningly, the operators working on the day of the incident were recorded to have been consecutively working 12-hour shifts for at least the past 29 days and were likely to have been highly fatigue. This would have had a large impact on impairing their performance and decision-making abilities, hindering them from diagnosing the underlying cause of the issue. Alternatively, the main causes for the lack of technically trained workers were that the operator training program was inadequate and management did not place much importance on training within the company. The isomerization unit training program failed to address the relevant theories underlying the process nor taught them how to manage abnormal or potentially hazardous situations [6, 7]. The on-the-job training primarily only covered the day-to-day routine activities, while occasional procedures such as start-up and shutdown were only reviewed if training happened to be scheduled during that period. It also lacked an effective means of verifying that operators had the necessary understanding and qualifications for operating the unit and handling abnormal situations safely [7]. Operators were found to often deviate from the start-up procedures, which they deemed outdated and ineffective, and considered it acceptable to develop their own practices to resolve the unaddressed reoccurring issues [6, 7]. Most critically, in the 6 years prior to the incident, corporate management gradually shrunk the training department and overlooked its essentialness to operation. They reduced the number of training staff from 28 to 8, cut their budget in half from $2.8 to $1.4 million, and assigned trainers to other duties such that only 5% of their time was actually spent on training workers [6]. Another human error with a significant impact on this incident is lack of effective communication as BP did not have any communication requirements nor reinforced any policies on the operators and supervisors during shift turnover. In the shift changeover prior to the incident, the departing operators only left a brief and vague note for the oncoming operators, which led to miscommunication of critical start-up information that could have helped mitigate the incident [7].

2.1.1.2 Synthron Runaway Chemical Reaction and Vapour Cloud Explosion

On January 31, 2006, a runaway chemical reaction occurred at Synthron, LLC due to inaccurate scale up of a recipe order, which doubled the exothermic energy release rate in the reactor such that its cooling capacity was exceeded. As the pressure in the reactor rapidly increased, solvent vapours were vented out in the form of a flammable cloud within the facility and ignited upon contact with an ignition source. This set off a vapour cloud explosion and fire that resulted in casualties of 1 dead and 14 injured, severe damage to the production facility and nearby community structures [8].

The incident arose when Synthron received an order for 12% more materials than they would normally produce in a standard batch. The managers considered this as a very small increase in material and decided to just scale-up their usual recipe to produce the entire order within a single batch. Horrifyingly, on the day of the incident, Synthron did not have any engineers on staff who could have evaluated the hazards of the reactive operation. Instead, all the employees on shift had only been employed there for under a year and lacked prior experience regarding polymer manufacturing. The plant superintendent had simply proportionally scaled up the ratio of recipe ingredients without considering the changes on the underlying principles of reactive chemistry from the scale-up and its effect on reactor functionalities. Historically, this scale-up procedure has been an estimated trial-and-error process, where batch quantities were gradually increased based on past experience until it approached a performance limit. Synthron's inadequate operator training program and lack of emphasis on hazard recognition and response were the main human error root causes that led to operators deviating from the operating procedures and having a lack of understanding of the critical principles involved in the process and resulting in this catastrophe [8].

2.1.1.3 Bayer Pesticide Chemical Runaway Reaction and Pressure Vessel Explosion

On August 28, 2008, a runaway chemical reaction occurred at Bayer CropScience during the restart of a methomyl unit after a lengthy outage when the process control system was upgraded and the residue treater in the unit was replaced. The solvent containing methomyl was erroneously added into the residue treater before it was filled with clean solvent and heated to at least the minimum required operating temperature as indicated in the operating procedure. This newly installed residue treater pressure vessel ruptured and violently exploded, spraying about 2,2000 gallons of highly flammable solvent that instantly ignited and burned for over 4 hours. The amount of energy released from this explosion was estimated to be equivalent to 17 pounds of TNT. Two operators originally dispatched to investigate the issue behind the rising pressure in the residue treater died in the explosion, while 8 contractors or firefighters on the scene were treated for potential exposure to toxic chemicals. Additionally, the fire and smoke caused traffic closure in the nearby roads and highways for hours, overpressure damages to structures up to 7 miles from the source, and a shelter-in-place order was issued that forced over 40,000 residents to remain indoors for over 3 hours as a precaution [9].

CSB determined that a major human error root cause that resulted in this runaway reaction and failure to contain the release of toxic chemicals was that the operators had deviated from the written start-up procedures to the extent that they even bypassed critical safety devices that would have prevented this incident. Part of this problem may be due to the poorly designed training manual, which was not written in the perception of the user nor included the actual procedures required to run the control system. The newly installed control system was also significantly more complex than the old system and operators needed to be retrained to familiarize themselves with operating the new system and using different units of measurement to read process variables. The operators working on the day of the incident were found to lack sufficient technical expertise and training on using this new control system. They had received training with the control system on another unit but management had deemed it unnecessary to provide practice with using this system on the methomyl unit, which resulted in these operators only having minimal on-the-job and self-directed training running general methomyl processes. As unfamiliarity and routine changes negatively influence operator usability, leading to a delay in response time and awareness, this human error was likely to have largely impaired the operators' ability to respond quickly and appropriately to mitigate the emergency in time. Furthermore, during shift turnover communication between the operators, several key details were inadequately addressed that led to deviation of critical start-up procedures and the eventual explosion. The emergency response team was also confused due to poor communications between the Bayer incident commander and the local emergency response agency, which delayed their assistance on the scene and notification to the public on how to minimize risk of exposure to toxic chemicals [9].

2.1.2 Common Sources of Human Error

A research study [10] interviewed 38 maintenance employees from a major gas and oil production facility. They were asked to recall a past failure they were personally familiar with and about the influence each of the 27 human factors considered by HFIT (human factor investigation tool) had on it. Table 1 lists the most frequently recurring performance shaping factors found in maintenance-related failures. From this table, competence and training is seen to be ranked quite high on the list (rank 8), occurring in 42% of the cases. Some related factors include mistaken assumption (rank 1) in 79% of cases and decision-making errors (rank 5) in 55% of cases, both of which are related to problem-solving ability [10]. In face of abnormal situations, many operators attempt to resolve the issue based on their past experiences, often without sufficient or accurate information to support their decisions. However, if these operators had been trained on the necessary concepts and safety knowledge, could this understanding have potentially helped them in making wiser decisions? Another factor of interest is procedure violation, which was reported in only 18% of cases in the interviews and ranked fairly low (rank 22), although it is quite prominently discussed in organizational psychology and management literatures. Some related factors include inadequate procedures (rank 7) in 45% of cases, inadequate work preparation (rank 9) in 39% of cases, and sequence error (rank 27) which was not reported by workers [10]. These performance shaping factors highlight the importance of having good procedures and manuals that can direct operators on what to do given different scenarios, as well as to adequately prepare and train them to respond appropriately in case of an accident.

Rank	Performance Shaping Factor	No of times Reported	% of cases
1	Assumption	30	79
2	Design and maintenance	27	71
3	Communication	25	66
4	Omission	22	58
5	Decision-Making	21	55
6	Information	17	45
7	Procedures	17	45
8	Competency & Training	16	42
9	Work Preparation	15	39
10	Organisational Culture	15	39
11	Detection	15	39
12	Policies & Standards	15	39
13	Job Factors	14	37
14	Timing	14	37
15	Attention	12	32
16	Selection	12	32
17	Supervision	11	29
18	Work Environment	11	29
19	Work Quality	10	26
20	Teamwork	9	24
21	Person Factors	8	21
22	Procedure Violations	7	18
23	Memory	6	16
24	Human-Machine Interface	5	13
25	Interpretation	4	11
26	Execution	2	5
27	Sequence	0	0

Table 1: Rank of HFIT Performance Shaping Factors in Manufacturing-Related Failures [10]

Another study [11] focused specifically on the procedural practices in refining and chemical operations. The researchers conducted a field study to assess the root causes for procedural breakdowns through examining incident reports and interviewing key personnel from 4 chemical and refining sites on their experiences with using procedures and other supporting technologies. From Table 2, the top 2 most common root causes for procedural breakdown were found to be incomplete coverage, present in 42.7% of incident reports, and procedure not followed, present in 29.0% of incident reports. Employees were also surveyed on their perception of common root causes for procedural breakdowns and their relative frequency. The most common root causes mentioned were that the procedures were not referenced and operators created shortcuts in the procedure to save time. Although occurring rather infrequently, operators' lack of knowledge and experience and the incomplete coverage of relevant training materials within the manual were also reported to occur more than once each month [11].

Root Cause Description	%
1. Incomplete Coverage	42.7
2. Procedure NOT Followed	29.0
3. Flawed Reasoning	13.7
4. Incorrect Procedure	6.1
5. Incorrect Use of Procedure	3.8
6. Inadequate Coordination	3.1
7. Incorrect Data/Facts	1.5

Table 2: Root Cause for Procedural Breakdowns [11]

2.1.3 Low Risk Industries

The research study in this thesis focuses on *low risk industries*, such as food, beverages, plastics and paper manufacturing plants, that have a relatively lower risk of resulting in severe accidents compared to *high risk industries* like nuclear power plants and gas and oil refineries. Due to being in a more hazardous environment, operators working in high risk industries are more conscious of the severity of inappropriate system operation. These companies likely have more extensive training programs and both the company and operator make a significant effort to ensure operators are adequately trained in process knowledge and operation skill. On the contrary, in low risk industries where the consequences of mistakes and deviations from written procedures seem less severe, companies may attempt to simplify employee training to save money, time and resources. Similarly, these operators tend to only focus on knowing how to operate the system, while placing low importance on understanding the principles of process operation, due to lower perceived risks associated with lack of understanding why.

Many news articles have reported accidents in low risk industries that could have been prevented or mitigated, had the company implemented appropriate safety procedures and had employees received adequate training. In the summer of 2008, Maple Leaf Foods experienced a listeriosis outbreak that caused 22 deaths and hundreds of consumers to fall ill after eating tainted meat due to an inadequate food safety culture [12, 13]. This incident resulted in a $27 million lawsuit, the recall of all 220 products produced at Maple Leaf's Toronto plant where the outbreak originated, the recall of many other products sold by clients of Maple Leaf, and lost of consumer confidence in Maple Leaf and the overall food inspection system [12]. Learning from their mistake, the company undertook drastic measures to enforce the principle "everyone owns food safety" in action. Instead of having good manufacturing practices strictly overseen by the quality department, the company developed a new inspection system that involved all employees participating in several layers of top-down inspections. Inspection cards, which contained written requirements and diagrams of how things should look if executed properly, were distributed among the employees as coaching tools to be used alongside the guidance of associate employees who would correct errors and explain why certain requirements were essential to food safety. In this manner, Maple Leaf emphasized to all its employees the importance of food safety and made everyone accountable for the products they produced [13].

In an article by Neal et al. [14], they acknowledge the workforce to be the most critical success factor to food safety programs since employees are the ones who oversee and contribute to food safety issues on a daily basis. Due to increasing diversity in workforces, non-English-speaking employees have been found to be more reluctant to communicate food safety practices and issues with managers compared to English-speaking employees, thereby increasing safety risks and lost of productivity. However, with the high turnover rates in the food industry, managers tend to invest less time, money and effort into food safety training programs, creating a situation where inadequate training, insufficient training resources, and lack of concern by both management and employees regarding providing adequate employee training are major barriers to creating a positive food safety culture within the company [14].

In October 2015, an operator at the Clearwater Paper mill in Ladysmith, Wisconsin, United States was killed while performing maintenance on a high-speed conveyor belt. The Occupational Safety and Health Administration concluded that this death could have been prevented, had the employer taken adequate machine safety procedures to ensure the equipment was powered down and locked out prior to being serviced. Further investigation showed that this was actually a common occurrence in the plant, where operators often worked while high-speed conveyers and machines were still in operation [15].

2.2 Human Error Reduction

Many accidents caused by human error are due to employee negligence and could have been prevented. Data collected from the state administration of work safety in China between 2005 to 2009 showed that although the total number accidents and the total number of deaths due to accidents decreased each year, more than 80% of these accidents each year were still caused by human error. Just in the year 2009, 83,196 employees died from a work-related accident in China [16]. Especially considering that this large fatality count is only for one country, it is evident that companies need to take active measures towards human error reduction as safety is a basic human necessity and it is the company's responsibility to ensure a safe working culture [17]. A research study by Ng et al. suggested that while familiarity with office equipment can significantly reduce human errors, it may not necessarily reduce the overall occurrence of accidents within the company [18].

A human performance enhancement programme was developed for British Energy in an attempt to reduce the significant nuclear power incidences caused by human error. Some of the underlying principles on which this programme was designed are that while everyone makes mistakes, these errors can be predicted and steps can be taken for prevention in many situations. Thus, it proposes that mistakes can be avoided if operators understand the reason why they occur and learn from past mistakes. Based on these principles, British Energy established 10 human error prevention tools as a standard for their company, among which are procedure use and adherence, operating experience, observation and coaching and clear communication techniques [19].

In a study [3] of manufacturing deviation reports at BioPhorum companies, human error was identified as the root cause for the deviations in over 50% of the incidents. In majority of these cases, the company chose to retrain the workers involved by having them reread the relevant standard operating procedures and validating with a supervisor that they properly understood the procedure as a corrective action. However, further analysis suggests that this approach is insufficient for resolving the problem and the same deviations reoccurred 47% of the time [3]. This same method of retraining workers is also used by many companies as it is the simplest and quickest approach to having operators going back to work on the production line after refreshing their memory of the correct protocols during operation. However, results of this study indicate that this method is insufficient and companies need to take more appropriate corrective actions to reducing human error.

Another research study [20] conducted an accident investigation on database records obtained from the Center of Prevention of Occupational Risk to identify the workplace and organizational factors underlying these incidents. Forty manufacturing accidents from 2000 to 2008 within Greece were examined using the Method of Investigation by Labour Inspectors. Data shows that more than 50% of the accidents involved unskilled workers, and similarly, over 50% were caused from operating a machinery. These results suggest that one method occupational accidents can be prevented is by providing operators with adequate training and safe equipment [20]. This study also highlights the importance of training within a company to promote a safe working environment where all workers are familiarized with process equipment prior to going out on the job [21].

2.2.1 Existing Examples of Fail-Proof Systems

Due to the prominence of human error, many industries have taken preventative measures to reduce or eliminate its impact on the overall process. A simple example is lockout or tag out devices, which are used to physically lock the system into a safe mode for cleaning or maintenance-purposes by isolating it from contacting a source of power (i.e., locking plug, power switches and buttons in a closed container so they cannot be accessed). The placement of this lock or tag onto an energy-isolating device indicates that the system is not to be operated until the lock or tag is removed. As each tag consists of slots where several locks can be placed, one for each relevant personnel who keeps the key with them, this ensure that anyone working with the equipment would be aware of when the system is in operation once again. This safety procedure is required by many companies to prevent accidents from occurring due to unintended start-up of machinery or release of hazardous energy. It also ensures workers' safety and that they are not in close contact with the system, cleaning or performing maintenance on it, under the hazard that it could start-up at any time [22].

Another widely used strategy is poka-yoke, also known as mistake-proofing, which was developed in the 1960s by Shigeo Shingo to reduce human errors in industrial processes. Although this method lacks theoretical grounding, it has been proven to work through many anecdotal evidences. Specifically, Toyota is one of the many companies that widely use poka-yoke devices to facilitate inspections due to their low costs and ability to significantly reduce inspection time and costs to near zero. These devices are comprised on sensors, alarms and limit switches that operate by either preventing a mistake from happening or making the mistake obvious and noticeable to operators. There are 3 main quality control inspection techniques in which poka-yoke devices generally compliment: 1) judgment inspection, which ensures that defects do not leave the company by inspecting 100% of the goods and separating defective products from acceptable ones; 2) informative inspection, which decreases the likelihood of a defect by gathering production data and using it to control the process (e.g., statistical process control, self-checks); and 3) source inspection, which aims for zero defects by determining prior to production whether the operating conditions required for high quality manufacturing exists and either stopping production until the improper conditions are resolved (e.g., control poka-yoke devices) or notifying operators of the improper conditions but allowing production to continue (e.g., warning poka-yoke devices). By incorporating poka-yoke devices into the production process, operators will be able to identify a defect in the product the moment an error occurs, enabling them to trace back to the circumstances which caused the last unit to be defective, thereby enhancing quality control [23].

2.3 Effect of Lack of Understanding on Human Error

Although many accident investigations have cited lack of understanding as a root cause of many incidents, research has yet to be done with regards to studying whether understanding can really reduce human error and the extent to which this is true. An example of a study where knowledge was measured as a variable that could affect human error was in a research paper by Reason [24] on how to take a systems approach to organizational error. This paper contains a model of accident causation (Figure 1) suggesting that accidents occur when the last line of defense collapses and fails to prevent humans from making errors and violations within a workplace that induces error-and violation-producing conditions. Of the many variables used in this study to measure accident-producing factors, 2 local factors examined for short-term indication of organizational error were knowledge, skills and experience, as well as paperwork, manuals and procedures [24]. This experiment is an example of one of the many research studies where authors recognized the importance of understanding on process operation and measured it as a factor affecting organizational error.

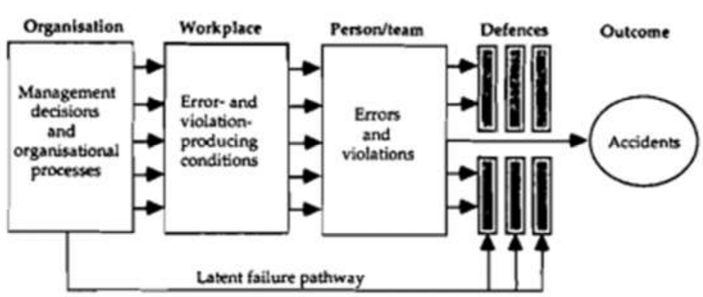


Figure 1: A Model of Organizational Accident Causation [24]

2.4 Effect of Training on Human Error

Training can be described as a systematic and planned effort by the company to impart knowledge and skills onto trainees through learning experiences to enable them to achieve effective performance in particular situations [25, 26]. It is an essential strategy used by all companies to educate employees on the knowledge and skills necessary to respond to workplace challenges [27].

There are many different forms of training, such as simulations, case studies and training workshops. Most simply, training can be classified between on-the-job training and off-the-job training. During on-the-job training, which is the type of training usually used in industries, employees typically participate in a course that explains the new processes, procedures and regulations in the company and are then expected to apply this abstract knowledge into their work. It focuses on getting the job done by developing best practices on how to operate the process and resolve issues that may arise in the workplace. Some well-known forms of this type of training includes apprenticeship training and job rotation, where employees get an opportunity to learn and practice technical skills while working on the job. On the contrary, off-the-job training emphasizes on learning basic fasts and skills from a given curriculum. Some examples include classroom lectures and simulations. Its ultimate goal is to convey specific information that are static, generalized, and decontextualized, which may be suitable for developing technical and problem-solving skills [26].

2.4.1 Importance of Training

In a study [28] of the effectiveness of safety procedures and management, activities that are susceptible to human error were identified using the Success Likelihood Index Method for human reliability assessment. Of the most common human errors, the researchers identified incomplete implementation of safety measures and breach of field operation protocol to be among the top 10. As a means against these errors, training practice, procedure type and quality, and time pressure are major performance shaping factors of employee performance, with procedure being the most important factor that is taken into account first when attempting to reduce human error. Training was found to be the second most important factor as insufficient knowledge on the correct procedures required to operate the system, especially in emergency situations, is a major cause for human error [28].

A study [29] by Alfandi examined the effect of training on enhancing employee performance at Jordanian travel and tourism institutions. Results confirm that training has a vital role in significantly improving employee performance in terms of quantity, quality and speed of work achievement [29]. Many other research findings have similarly shown that receiving training of any form will improve employee performance, including physical task-related training [30], cognitive spatial visualization training [31], and virtual reality training [32]. Research also shows that both group training and individual coaching can significantly reduce procrastination and facilitate goal attainment. It suggests that group training is more suitable when companies need to systematically prepare workers to perform specific tasks due to its lower costs, while coaching is more suitable when emphasizing certain aspects of the company's working conditions or the development of individual worker's goals [33].

2.4.2 Industrial Impact of Training

While training is often only considered for new employees in many companies, when in fact, all employees should undergo ongoing training to continuously improve themselves as it will aid them in rapidly adjusting to the demands of the varying job requirements [34, 35]. Setting goals will also enable companies to better evaluate and upgrade the training program, while employees who set goals for themselves tend to have a higher probability of success. In a study comparing the 4 learning barriers of situational, institutional, informational and psychological to training and learning within an organization, results indicate that employees with higher education qualifications encounter less learning barriers when adopting information and communication technology skills [34].

In another paper [36], researchers examined trainee and environmental factors that affect the transfer of learned training materials to the workplace. An example of a trainee motivation-related factor indicates that trainees who perceived greater relevance of training program was found to more effectively increase motivation and transfer of training, while a trainee ability-related factor indicates that trainees with higher knowledge acquisition and retention are better prepared and able to apply the concepts learned to the workplace. On the other hand, an example of a job-related environmental factor indicates that trainees provided supervisory support in the form of guidance and feedback will be able to more positively reinforce their application of learned knowledge [36]. Results of another study further suggests that interactive training programs and clarity of the trainer when responding to questions facilitates a more lively and interesting session with greater participant involvement, which in turn leads to better comprehension and retention of training materials [37].

2.5 Training Manuals

Research of how to compose effective training manuals have expressed the need for it to be well-written, attractive, well-formatted so it is easy to follow, and illustrated appropriately with diagrams to enhance understanding. Authors need to appropriately distinguish between information that needs to be included and those that should be excluded when composing manuals, with the rule-of-thumb being to only include information that the user needs to know to operate the system [38]. Specifically, training manuals should highlight areas of concern in the procedure and include relevant safety and maintenance information, common troubleshooting and problem-solving procedures, and specific operating limits and parameters that must be satisfied. Researchers also recommended that the manual be written by more than one person to obtain multiple perspectives of the operation and by an operator other than the manufacturer of the system to ensure the procedure takes into account the difficulties that inexperienced operators may encounter [39].

Researchers stress that a training manual must be designed with its readers in mind as regardless of how well it is written, if employees are unable to use it then the manual is defective [38]. For a manual to be learner-friendly, there are several aspects of its appearance that should be noted. First and foremost, it needs to satisfy its purpose of being a convenient reference tool as it will likely be used throughout the course of the operation even after the training session. Authors can consider indexing the manual to make it easier to reference certain subjects and making each manual's cover distinct to enable employees to quickly distinguish its contents in the case employees are given several different training manuals. Appropriate use of graphics and colour can also accelerate learning and maintain user's interest. Market research showed that colour can increase readership by 40% and user's degree of learning and retention by a maximum of 78% [40].

2.6 Procedural Knowledge

The Abnormal Situation Management (ASM) Consortium, which is comprised of a group of experts from leading companies and universities, compiled a comprehensive set of procedural guidelines based on research and industrial best practices proven to be reliable both within the field and by subject matter experts. Its aim is to improve the development of well-designed procedures, such that it can be effectively used by operators during both normal and abnormal situations. According to the ASM Consortium, the use of effective procedures can improve operator awareness and execution consistency, thereby reducing the frequency of abnormal occurrences [41]. Two of the most common reasons for procedure execution failure in abnormal situations are not knowing what an appropriate response would be and having an inaccurate understanding of the effect of procedural action or the effect of not adhering to procedural instructions [42]. These reasons suggest the importance for operators to have procedural knowledge, also described in this thesis as the understanding of underlying principles regarding process operation, that would enable then to sufficiently understand the process to know the impact of a certain action or inaction. The ASM Consortium supports this hypothesis, as seen from the objective of their recommended training procedural guidelines, which is to develop operators' knowledge and skill such that they understand the underlying rationale of the procedural management system and execute the instructions effectively in a safe and efficient manner [42].

Although many researchers [10, 11, 24], the CSB [6, 7, 8, 9] and the ASM Consortium [42] recognize the importance of incorporating procedural knowledge into training and ensuring operators understand the underlying rationale, research has yet to be conducted to determine whether procedural knowledge can really improve operator's process operation and the extent to which this is true. Specifically, this thesis focuses on training using only procedural instructions incorporated within written manuals and whether the incorporation of procedural knowledge would improve operator's performance, emergency response, procedural adherence and understanding. Although no similar experiments were found to be conducted by other researchers on any of these factors relating to procedural knowledge, a research study related to procedural adherence was performed by Guerlain and Bullemer [43]. The authors examined whether the use of an interactive critiquing system, a computerized system that monitors operator actions to support their decision-making and prevent errors, would aid the execution of complex procedures which may require the cooperation of multiple operators. This experiment and critiquing system was developed in accordance to the reactor start-up, operation, and shutdown procedures used at a major petrochemical refinery. It displays the entire list of procedural steps and keeps track of each operator's progress in real-time, through the use of a wearable computer systems for field operators and traditional computers for control room operators, but is designed such that steps dependent on a previous step will only be enabled when its prerequisite step has been completed. The results of this study indicated that the critiquing system was effective for reducing procedural errors and enhancing operator performance for difficult tasks. It enabled the users to more easily coordinate as a team, to keep track of the overall progress of the operation, and to be organized with performing the procedural steps in their required sequence [43].

2.6.1 Effect of Comprehension on Training

An article [44] on the automotive sector examined the effect of employee training on cost reduction of the final product. As part of the learning curve, as operators gain a better understanding of the overall process, they will be able to better contribute their ideas to the enhancement the operation and react more effectively to unforeseen circumstances [44]. However, training was found to be a critical factor for achieving high productivity [45, 46] and which led to increased sales [47], higher quality [47, 48], and greater customer satisfaction [47, 49]. Majority of the problems that occur during manufacturing were caused by a lack of training received by operators and lack of knowledge regarding the effect of process parameters on the final product [45]. Thus, one study [50] examined the effect of simulator training on improving operators' knowledge of diesel filter production processes and management of machine parameters. Results indicate that operators who received this simulated training had better process knowledge than others, which led to increased productivity due to time reduction from technical and organizational losses when implemented on-site. This simulation was also reported by operators to be a useful and easy to use tool that explains the aim and rule of the simulated training [50].

2.7 Effect of Motivation on Training

Many research studies conducted on the relationship between training and motivation has proven that motivation has a significant influence on training effectiveness, which encompasses employee willingness to participate in training, the amount of effort they put into training, and the ability to apply what they learn from training to the job. In contrast, when employees lack motivation, they will be unable to reap all the benefits the training session has to offer as employees require both the capability and the motivation to learn in order to achieve good performance [25, 27]. Thus, this stresses the importance of empowering employees by motivating them and improving their morale as it is a key to improving performance [51].

A research study [25] of human resource development construction firms in Iran studied the relationship between employee's training practices and motivation on the performance of the company. Analysis of employees' questionnaire survey reinforces that motivators can highly increase the influence of training practices on teamwork activities and task efficiency [25]. Another study [27] examined the effect of training assignment and training motivation on trainees' perceived importance of a Taiwan Academy of Banking and Finance training program. The results indicate that participants whose supervisors instructed them to participate in the training session had higher perceived importance and familiarity with training contents, which in turn increased their motivation towards training [27].

Since training effectiveness is largely influenced by motivations, companies are advised to develop ways to motivate employees. There are many types of motivators that can be used and organizations or teams should find ones that work best in motivating their members. A study by Kovach [52] compared what employees desired from their work with what managers thought employees desired. While many managers thought employees were most interested in high salaries and least interested in interesting work, the reverse was actually true for the employees [52]. Instead, some rather simple key actions that managers can perform, which have substantial influence on motivating workers include: thanking and acknowledging workers, providing them with honest and specific feedbacks, encouraging ideas and the sharing of information, and establishing a trustworthy and respectful work environment [53].

Another factor that is found to influence training effectiveness is the employee's life cycle. Overall, self-assessed training effectiveness is found to be higher for employees who worked for a longer duration but have no intention to quit in the near future, are healthy and have high qualifications. This paper [54] suggest that older employees have lower training effectiveness and motivation to participate in training because companies fail to take their preferences for specific training needs and interests into account when conducting training. This group of older employees are found to prefer and have higher effectiveness when trained using time flexible training forms that are more practical and relevant to every day problems as compared to more abstract and formal training forms [54].

Chapter 3
Experiment

Chapter 3 describes the method used in this research study to examine the importance of understanding during training to determine its effect on operator performance, adherence to instructions, emergency response, and retention of learned knowledge and skills during operation of an industrial process. Participants were recruited to participate in this experiment, where they read over a randomly assigned training manual (from two options) and then operated a simulated industrial hydraulic pump system based on the information and procedures given. Throughout the experiment, participants completed a variety of surveys and questionnaires aimed to query their opinions on using various training materials and to assess their understanding of important operating skills and concepts. All materials used in the experiment have been included in Appendix A.

3.1 Objectives

The objective of this experiment was to compare the effects of using a procedural training manual verses an explanatory training manual to operate a hydraulic pump system. Currently enrolled university students who were recruited as participants were also compared across their educational background and categorized into 3 groups: chemical engineering, other engineering and other faculties. Participants' proficiency was evaluated according to the following 4 aspects of process operation: 1) performance in terms of operation speed and accuracy, 2) adherence to the procedure listed in the training manual, 3) ability to respond appropriately and accurately under limited guidance during an emergency situation, and 4) amount of learned knowledge and skills retained after a 2-week period as measured by degree of accuracy in answering questionnaire.

3.2 Hypothesis

It is hypothesized that participants assigned an explanatory training manual would outperform those assigned a procedural training manual in all 4 aspects of proficiency. Since the explanatory manual contains relevant concepts explaining the mechanics of how the process controls function and the underlying fluid mechanic theories of how the process operates, this information was hypothesized to give participants a better understanding of the system as a whole and on how to manipulate certain controls to achieve certain effects on process parameters. In turn, this understanding was theorized to improve the performance of participants assigned an explanatory manual, in terms of both having a higher degree of accuracy in maintaining the operating criteria of inlet flow rate and pressure drop within the required range and completing each production task within a shorter duration of time, compared to those assigned a procedural manual. The explanatory manual also contained notes inserted between certain steps that explains why particular procedures are important to be followed and certain sequence of steps must be performed in the specified order, so to make clear to participants why they should adhere to these instructions even though they may seem unnecessary, tedious, and overcomplicated. These explanations were hypothesized to increase participants' adherence to instructions for those who used an explanatory manual as compared to using a procedural manual. Having an enriched understanding from reading the explanatory manual, coupled with the application of this knowledge while experimenting with the system, is hypothesized to improve participants' emergency response in better knowing the appropriate courses of action to undertake and reaching the end goal as quickly as possible compared to those who read the procedural manual. This is also theorized to result in participants scoring higher on the post-test questionnaire and retaining more knowledge during the retention-test questionnaire if they were assigned an explanatory rather than a procedural manual due to a more solid foundation of understanding and application during operation.

Of the 3 educational backgrounds, chemical engineering participants were hypothesized to outperform those from other engineering backgrounds, who were in turn hypothesized to outperform those from other faculties in all 4 aspects of proficiency. Chemical engineering participants were expected to have the most prior knowledge and experience relevant to operating the system, while other engineering participants were expected to have a moderate amount and participants from other faculties were expected to have a negligible to minor amount. This pre-existing background knowledge and experience are expected to help participants have a better understanding of how the system operates and familiarity on how to appropriately manipulate process controls even before reading the manual, such that the information presented mainly serves to refresh their memory and remind them of certain key concepts. Due to having previously used or come into contact with fluid mechanic, process operation and pump system vocabulary, these participants are also expected to have better technical understanding of the material presented in the manuals and the questions asked in the surveys and questionnaires. Thus, chemical engineering participants were hypothesized to have better performance, in terms of both accuracy and speed, emergency response during the overheating scenario, and to score higher on both the post-test and retention-test questionnaires compared to participants from other engineering backgrounds, who in turn performed better than participants from other faculties. As engineering programs and industrial settings where students may have had internships place high importance on accuracy and precision, these students are expected to have been influenced their environment and to understand the importance of following procedures or the potential consequences of not following them. Thus, chemical engineering participants and other engineering participants were hypothesized to have the same degree of adherence to instructions in the manual while operating the system, and both these 2 groups were hypothesized to have a higher degree of adherence compared to participants from other faculties, which may place more importance on reaching the end goal than on following the exact procedure outlined to achieve that goal.

3.3 Experimental Design

This research study employs a 2 by 3 between-subject factorial design to compare the proficiency of participants within 2 different manual conditions (procedural training manual and explanatory training manual) and 3 different educational backgrounds (chemical engineering, other engineering, and other faculties). For the training manual variable, participants were randomly assigned to either a procedural training manual or an explanatory training manual in alternating sequence of subject ID number. Although educational background could not be controlled, the researchers recruited participants such that approximately one-third would be classified within each of the 3 categories. The purpose of this condition was to determine and control the effect of prior background knowledge on the results of this study. Participants with a chemical engineering background were expected to have the most prior knowledge due to the concepts and system operation in this study being derived from common undergraduate chemical engineering teachings and laboratory experiments, whereas participants in non-engineering faculties were expected to have the least prior knowledge due to this material likely being beyond the scope of their education. For a more accurate measurement, participants also completed a knowledge background survey (pre-test questionnaire) at the beginning of the experiment to assess their pre-existing knowledge prior to reading the training manual and operating the system.

This experiment consists of 2 sessions. The first session is the main part of the study where participants' performance and adherence to instructions during both normal and emergency situations were measured as they operated the hydraulic pump system. They also completed a variety of surveys and questionnaires to assess their pre-existing and learned knowledge of process operation and to obtain their opinions regarding the use of various training materials. The second session of this study takes place approximately 2 weeks after the first session and examines participants' degree of retention of learned knowledge and skills.

3.4 Methodology

3.4.1 Participants

A total of 60 undergraduate and graduate students were recruited as participants from the University of Waterloo. Participants were recruited mainly through advertising on the university's graduate research participant recruitment website, e-mail (Appendix A.1.1), posters (Appendix A.1.2), and by word-of-mouth. As part of the educational background condition, the research team attempted to recruit approximately one-third of participants from each of chemical engineering, other engineering and other faculties.

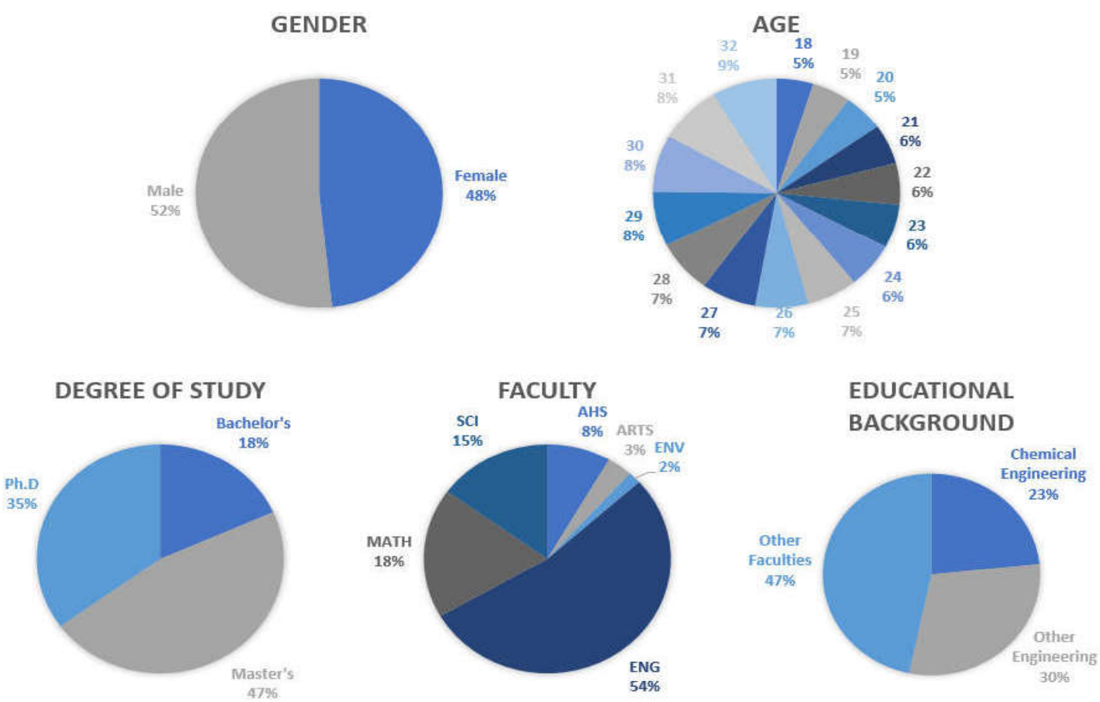


Figure 2: Demographic Statistics of Participants

Ultimately, of the individuals who volunteered for this study, 14 participants (23%) were recruited from the department of chemical engineering, 18 participants (30%) from other engineering departments, and 28 participants (47%) from all other faculties. Participants ranged from ages 18 to 32, spanning across all university faculties and degrees of study.

Figure 2 shows a breakdown of the demographic statistics of the participants recruited for this experiment. These results show that approximately half of the participants were recruited from each gender (52% male; 48% female), with the large majority being Master's and Ph.D (82%) students within the engineering, math and science faculties (87%) and between the ages of 23 to 30 (77%).

All participants received a remuneration of $30 for participating in session 1 of the study, which was approximately 2 hours in duration, and $10 for participating in session 2 of the study, which was approximately 30 minutes in duration. Those who required more than the estimated time to complete a session, were remunerated an additional prorated amount of $10 per hour of overtime.

3.4.2 Apparatus and Tasks

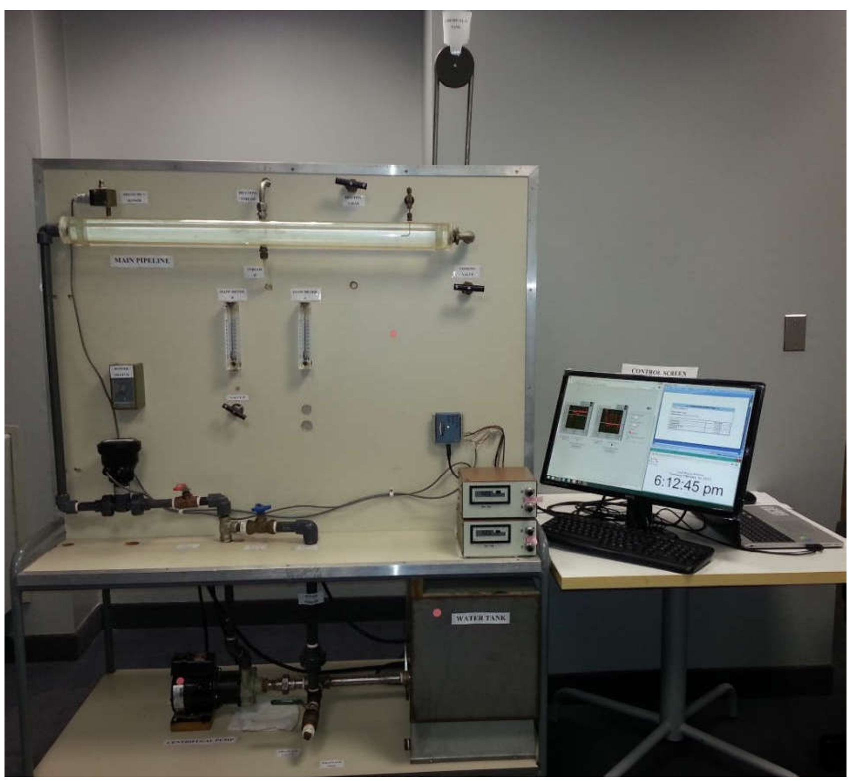


Figure 3: Experimental Setup (Front View)

As part of this experiment, participants operated a hydraulic pump system apparatus. Figure 3 shows the experimental setup used in this research study. This system was selected by researchers as fluid mechanics is a fundamental area of study in chemical engineering and hydraulic pumps are prominently used across many industrial processes. Furthermore, to ensure that even novice participants can understand and perform the experiment after the training and practice, only the preliminary fluid mechanic concepts of flow rate and pressure were introduced and process operation was simplified such that participants were only required to manipulate several valves.

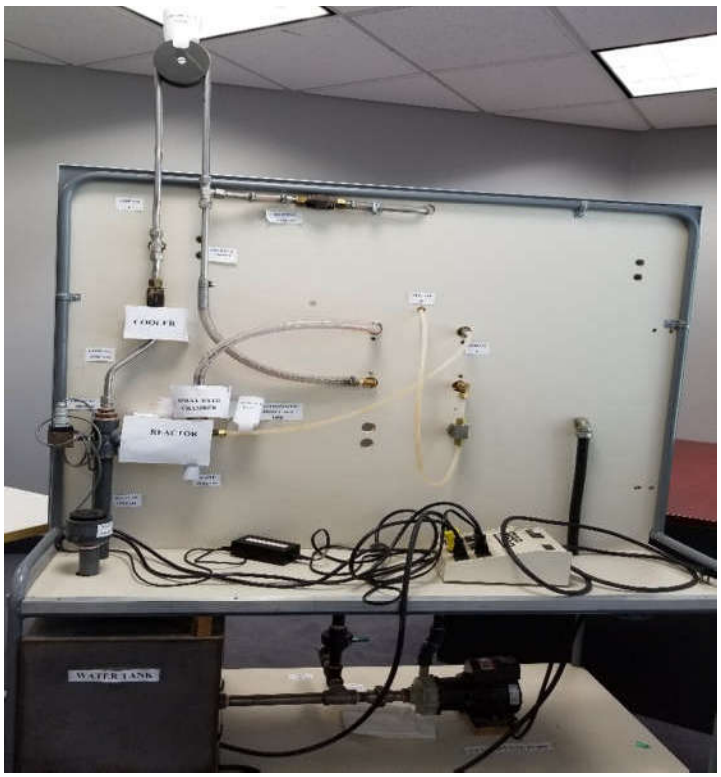


Figure 4: Experimental Setup (Back View)

The hydraulic pump system used in this experiment was specifically constructed to resemble a smaller pilot plant version of a hypothetical system that could be found in an industrial setting. I collaborated with the laboratory technicians from the chemical engineering department to design the system and install level indicators to create a simulated process environment tailored to the industrial case study presented in the training manual. To make the system more user-friendly and to prevent confusion due to overcrowding of system components, all process controls and indicators were mounted on the frontside of the apparatus, while majority of the piping for the various stream pathways were hidden on the backside. Figure 4 shows the piping and system components on the back of the experimental apparatus. The difficulty of this overall experiment was designed such that although novice participants can complete production tasks following the instructions in the manual, the manipulation of process controls required to achieve operational goals is not intuitive but requires some degree of learning, or recalling for knowledgeable participants, from the training materials.

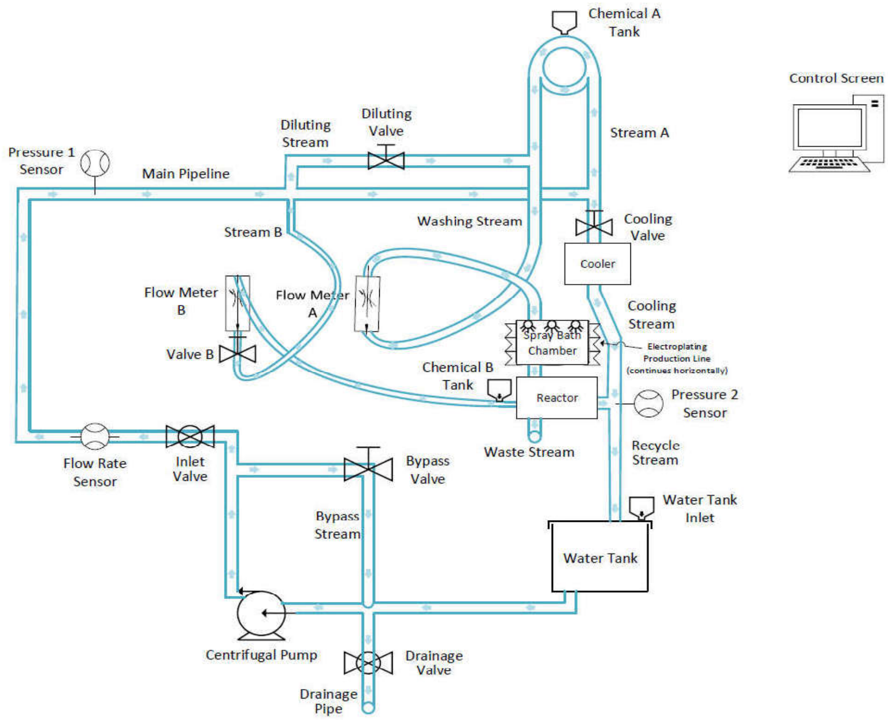


Figure 5: Schematic Diagram of Experimental Setup as Described to Participants

Figure 5 shows a schematic diagram of the hydraulic pump system as described to participants. This apparatus is a closed system that operates using a 115 VAC centrifugal pump rotating at 3400 rpm to continuously pump water from the water tank to an elevated height, where it is then diverted from the main pipeline into a maximum of 4 streams (washing stream, stream B, diluting and cooling streams) and cycled back into the water tank. This system also contains a bypass stream that branches off right before the inlet valve and is used to divert a portion of the excess flow back into the water tank pipeline so to help maintain the operating criteria within their required range. There are 6 valves in this system, of which participants operate 5 of them; inlet valve is used during start-up and shutdown, while the bypass valve, valve B, diluting valve, and cooling valve are used to adjust operating criteria and parameters within their required range. There are 2 operation parameters, washing stream flow rate and stream B flow rate, that participants need to respectively set at a specified range using the level indicators of flow meter A and flow meter B. Additionally, the flow rate sensor installed near the system inlet and the 2 pressure sensors, one installed near the system inlet and the other near the system outlet, are used to respectively measure the operating criteria of inlet flow rate and pressure drop across the system. These sensors are connected to a data acquisition device which collects and sends real-time data to the LABVIEW software. A control screen is located directly to the left of the system and consists of chemical input controls, visual alarms, and operating criteria level indicator displays. Figure 6 shows an illustration of the control screen used in this experiment. For safety purposes, no chemicals were used in this experiment, other than water flowing at room temperature throughout the system, although participants were instructed to operate the system assuming they exist.

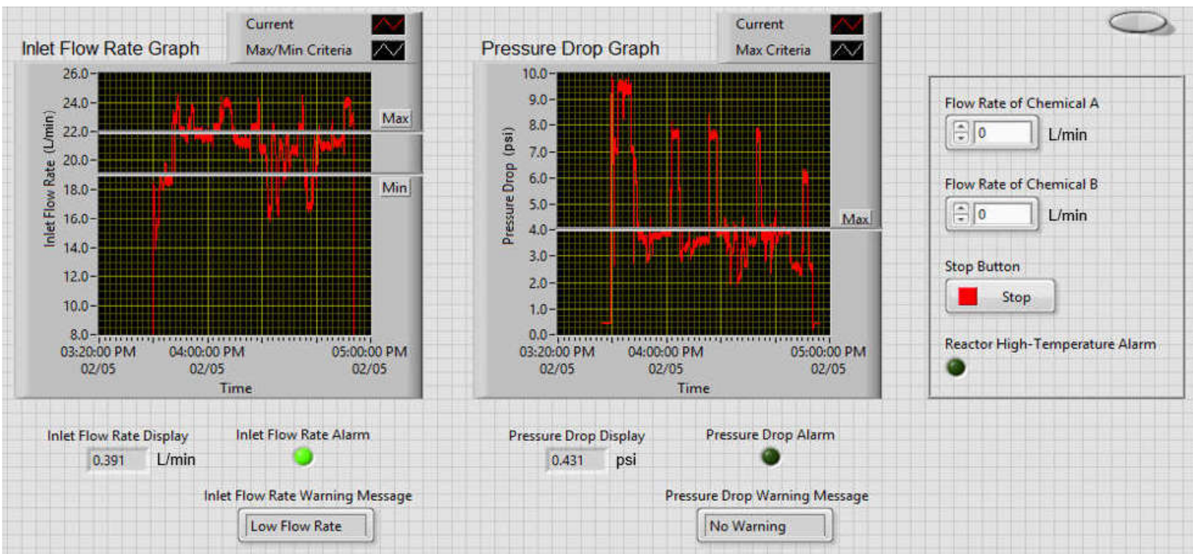


Figure 6: Control Screen

The participants were instructed to operate the system in accordance to the procedures in the manual (refer to Appendix A.3.3 for procedural training manual and A.3.4 for explanatory training manual). Overall, their objective during standard procedure operation was to ensure the following 3 operating criteria were met whenever the system was in operation: 1) maintain an inlet flow rate (L/min) within the range of 19 to 22 L/min, 2) maintain pressure drop (psi) less than 4 psi across the system, and 3) complete all operation instructions as quickly as possible. However, there was a slight change in participants' objective in the simulated overheating emergency scenario, such that satisfying the safety criterion and ensuring the temperature at the reactor exit is always kept below the critical temperature of 80 °C became top priority, while upholding the 3 operating criteria became secondary.

3.4.3 Procedure

This research study consisted of 2 separate experiment sessions. Session 1 is the main part of the experiment during which participants performed the simulated industrial case study and completed a variety of surveys and questionnaires that assessed their understanding and opinions of the study. Session 2 is the follow-up experiment that examines participants' degree of retention of skills and knowledge learned from session 1. Although session 2 was designed by the research team to occur 2 weeks after session 1, since many participants were unavailable exactly 14 days later, a flexibility of ±2 days was allowed.

Session 1

In session 1, participants were informed about the purpose of this study and the procedure they will be performing. Afterwards, they were given an information letter (Appendix A.3.1) to read over and offered an opportunity to ask the researcher any questions they had concerning the study. Participants were also informed that they may continue to raise any questions or concerns that arise at any time throughout the entire study. If the participant was still interested in participating, they were then given a consent form (Appendix A.3.2) to read over and sign.

Prior to the start of the actual experiment, participants were asked to fill out a demographic survey (Appendix A.3.5) and a questionnaire (i.e., pre-test questionnaire in Appendix A.3.6) that assessed their current level of knowledge and skill regarding hydraulic pump system operation and concepts. Participants were then given a training manual written in the form of a hypothetical industrial case study to read over, after which they would immediately begin the experiment with the first set of operation tasks being considered a practice trial.

In the experiment, participants were asked to operate the pump system in accordance to the procedures outlined in the training manual. As further explained in the manual, this experiment was performed assuming the participant was a new operator placed in charge of the wash system (i.e., the hydraulic pump system) at a metal manufacturing plant. It depicts a scenario where the manager is too busy to personally train the new operator and has just given him or her a training manual to read over and use while they operate a pilot plant wash system. In this training session, the pilot plant simulation is based on a hypothetical case study that compiles several common scenarios encountered during production throughout the process operation. Specifically, their task was to manipulate system controls to operate the various streams of the wash system and adjust their flow rates per order requirements (see control screen notifications in Appendix A.3.9), while simultaneously upholding operating criteria set by the company. While performing this experiment, participants had 3 objectives (i.e., operating criteria) that they were instructed to always aim to achieve: (1) maintain inlet flow rate within the range of 15-20 L/min, (2) maintain a pressure drop less than 2 psi and (3) complete all changes made to the system as quickly as possible. This case study consisted of performing a system start-up procedure, followed by 3 production orders of normal operation trials, an emergency response task, and finally a system shutdown procedure. The difficulty of this experiment was that participants had to manipulate 4 flow control valves (bypass valve, cooling valve, valve B and diluting valve) to set 4 parameters within the required range (inlet flow rate and pressure drop needed to be within the specified operating criteria range, while stream B flow rate and washing stream flow rate needed to be set to the required level or range of the production order in operation) and that all 4 valves had an effect on all 4 parameters. The overheating emergency scenario in this experiment consisted of 2 parts. The first part instructed participants to quickly cool down the temperature at the reactor exit as a top priority, while still maintaining process operation by ensuring operating criteria and parameters were kept within the required range as a secondary priority. If overheating persisted for over 2 minutes, participants were then instructed to disregard satisfying all operating criteria or parameters and simply use any combination of valves to cool down the system as quickly as possible.

At the end of this experiment, participants were asked to complete a questionnaire (i.e., post-test questionnaire) that assessed how much they learned about operating a hydraulic pump system and its related principles, as well as a practicality survey (Appendix A.3.8) that inquired about their usage of the manual and how helpful they found it to be in aiding their operation of the pump system.

At the end of this session, participants were given the solutions to the questionnaire (Appendix A.3.7) and given an opportunity to ask the researcher any questions they may have. They were then remunerated for participating in session 1, debriefed about the purpose of this experiment (with the exception of the retention aspect), and given a feedback form (Appendix A.3.11). The researcher then scheduled an appointment with the participant for session 2 of the study 12 to 16 days later and sent them an email reminder confirming their appointment the day before.

<u>Session 2</u>

When participants returned to participant in session 2 of the experiment 12 to 14 days later, they were asked to complete an additional questionnaire (i.e., retention-test questionnaire) that assessed how much learned knowledge and skills they retained from session 1. At the end of this session, participants were debriefed on the overall experiment and remunerated for participating in session 2 of the study.

3.4.4 Training Manuals

Manuals have been used for many centuries to record and pass down procedures on how a task should be completed. There are many different types of manuals used in a variety of settings, such as for running a production line or assembling a structure. In many industrial companies, due to lack of time and resources to conduct thorough employee training sessions, employees are often given a training manual to introduce them to the system and its basic operational aspects, in an attempt to reduce the overall training time required with an experienced operator. However, majority of these training instruction manuals are developed with the sole purpose of giving readers a list of steps detailing the course of actions they should undertake to ensure successful completion of the task, without any regards for ensuring readers understand why they should adhere to the instructions listed in the manual, why they need perform certain tasks, and the situations where it is or isn't appropriate to perform these tasks. This results in employees having to take the initiative to self-learn and experiment with system controls, often leading to the development of personal procedures based on what the employee believes to be the most appropriate and efficient way to operate the system. These personal procedures often stray from the established set of instructions in the manual and especially when developed by employees with no prior theoretical understanding or practical experience in the area, as often is the case, this can greatly affect process improvement opportunities and impede operators' ability to make appropriate decisions when emergency situations arise.

This research study compares the effect of 2 training manuals on the 4 measured factors of participant's level of proficiency. The procedural manual was designed to resemble a typical training manual that can be found in an industrial company. It consists of brief background information on the system and clear step-by-step procedures on how to operate process controls to complete production tasks in accordance to operation guidelines. On the other hand, the explanatory manual was designed to test the hypotheses of the research team and its effectiveness at improving operator proficiency in each of the 4 areas of study compared to the procedural manual. This manual contains important concepts relevant to process operation and explanations of why certain procedures and sequences are imperative to be followed, in addition to everything written in the procedural manual. Overall, while the *explanatory training manual* (ETM) describes both 'what' needs to be done and 'why' it needs to be done, the *procedural training manual* (PTM) only describes 'what' needs to be done.

The difficulty in designing these training manuals is that there is no universal layout or approach as to how they should be written. While some companies may use professional manuals written by a technical training staff, others may use manuals written by an experienced operator from a non-technical background. The training manuals used in this experiment were modelled after a combination of industrial training manuals and student laboratory manuals. Laboratory manuals were used as a template as they generally have uniform layouts across various fields of study and educational institutes. They resemble an industrial training manual that is geared towards a student audience and contains relevant technical concepts and step-by-step procedures to guide students on how to perform the experiment and operate the system. The scenarios in these manuals were presented as an industrial case study with tasks to complete various production orders and to resolve an emergency situation. This type of presentation was intentionally created to add realism into the study, such that participants felt they were involved with an actual process operation, in an attempt to motivate them to take this experiment seriously as if they were an actual operator-in-training.

For experimental purposes, the ETM and PTM were specifically constructed to exaggerate the differences in the information given. The information included in the PTM consists of only the most basic information necessary for participants to understand the system and operate it to complete production tasks. All important concepts and explanations of why certain procedures and sequences that may seem meaningless to follow are critical to process operation are only included in the ETM to examine if that may have an impact on improving the 4 factors of participants' proficiency as compared to using the PTM. In this experiment, participants were randomly assigned to operate the hydraulic pump system using either a PTM or an ETM in alternating sequence.

3.4.5 Surveys and Questionnaires

There were a total of 5 surveys and questionnaires that participants needed to complete throughout the course of this experiment. The demographic survey was completed by participants prior to operating the system. This survey consists of basic demographic questions as well as questions subjectively inquiring participants' current level of expertise in fluid mechanic concepts and pump system operation.

The 3 questionnaires that participants completed prior operating the system, immediately after operating the system, and after 12 to 16 days were respectively named the pre-test, post-test, and retention-test questionnaires for identification purposes. They are comprised entirely of multiple choice questions that examine participants' knowledge in the following 3 areas of the experiment: part 1 assessed their understanding of the overall hydraulic pump system, part 2 assessed their understanding of technical and safety knowledge relevant to process operation, and part 3 consisted of operation and scenario-based questions to assess their understanding of how to operate the system in various situations. All 3 of these questionnaires are identical, just with the questions and the multiple-choice answers within each question scrambled to ensure participants are selecting responses based on their understanding and not because they recall a certain selection is the correct answer.

The practicality survey was completed immediately after participants operated the system. In the first part of the practicality survey, the researcher interviewed participants regarding their goals and thought process while operating the system, their rationality behind certain actions, and their opinions on the different training manuals. The second part of the practicality survey consists of survey questions on each section of the training manual that inquires participants regarding how much they read, how much they understood, how practical they found the information, and how much of the information did they use to aid their process operation. As the explanatory manual consists of additional sections of explanatory information, the second part of the practicality survey was longer for participants assigned this manual as it asked the same set of questions but in reference to these added sections.

3.5 Data Analysis and Statistics

Data results for each of the 4 factors measured were gathered through use of a data collection device connected with sensors on the hydraulic pump system, unobtrusive observation by the researcher, and responses collected from the participant through interviews and survey questions. These results were then analyzed using the SPSS Statistics computer software and its built-in factorial ANOVA and repeated measures ANOVA programs.

A factorial 2-way ANOVA was used most frequently to analyze the effects of the 2 independent variables of manual and education on a number of dependent variables. For independent variables, this 2 by 3 ANOVA compares 2 different manual conditions assigned to participants (PTM and ETM) with 3 different educational backgrounds defining participants' current area of study (chemical engineering (CHE), other engineering (ENG), and other faculties (FAC)). The following dependent variables were analyzed to examine the effect of understanding on various aspects of participants' operational proficiency: 1) performance, 2) adherence, 3) emergency response, and 4) knowledge and retention.

Performance

For this factor, trial 1 of the experiment is considered a trial run for participants to become familiarized with operating the system and is not included in the analysis. Only trials 2 to 4 are analyzed but due to differences in their level of difficulty and parameters to be met, these 3 trials are not compared individually but rather an average is taken for analysis.

1. Task Completion Time

   Used to evaluate participants' performance in terms of time, this variable measures the average time in seconds required by each participant to complete a production order. It is measured through unobtrusive observation by the researcher and recording of the time at which participants began and ended each production task. The start time is measured from the first adjustment participants make to process controls in relation to the instructions on operating a production order, while the end time is measured from the instant operating criteria of inlet flow rate and pressure drop reach steady state within their specified range. These times were then used to extract the relevant sections of real-time data from the LABVIEW file for analysis of the following 3 dependent variables.

2. Percent Duration Within Bounds (PDWB)

   Used to evaluate participants' performance in terms of both speed and accuracy, this variable measures the average percent duration of time in which participants are able to operate the system such that the operating criteria of inlet flow rate and pressure drop are met. It considers that each participant and each trial required a different length of time to complete and uses real-time data collected by LABVIEW to calculate the percentage of time participants are within the specified bounds for each production order.

3. Z-Score Out-of-Bounds Integral (ZOBI)

   Used to evaluate participants' performance in terms of accuracy, this variable measures the average normalized z-score integral for out-of-bound ranges. As real-time process data is collected for each participant every 1 or 2 seconds throughout the experiment, the rectangle method is used to compute the approximate integral that each operating criterion of inlet flow rate and pressure drop remains out-of-bounds. These 2 integrals are then normalized and the average is calculated to determine participants' overall accuracy as they may use one operating criterion to compensate for another while operating the system until both criteria are met.

4. Z-Score Root-Mean-Square Error (ZRMSE)

   Used to evaluate participants' performance in terms of accuracy, this variable measures the average normalized z-score of root-mean-square error. The root-mean-square error is calculated from real-time process data for both inlet flow rate and pressure drop, then normalized and averaged to determine participants' overall accuracy in satisfying both operating criteria. Considering the specified range each operating criterion must be within, participants should ideally operate at the midpoint of this range and would typically hover near this value. Thus, the midpoints of 20.5 L/min for inlet flow rate (criteria: 19 to 22 L/min) and 2 psi for pressure drop (criteria: 0 to 4 psi) were selected as the reference mean values for calculating root-mean-square error.

Adherence

For this factor, trials 1 to 4 of the experiment are all included in the analysis as there is a possibility that after participants learned to operate the system in the first trial, they will choose to disregard certain procedures they found unnecessary for future repetitions. It is measured through unobtrusive observations by the researcher (see adherence checklist in Appendix A.3.10) while participants were performing the study to examine whether they adhered to each of the following dependent variables.

For participants assigned an ETM, a description was included to explain the purpose of each step within the overall production process and its importance to be completed in the specified sequence. As a reminder, a brief note was also included below certain essential steps in the procedure in case participants forgot or did not read over this section of the training manual. In contrast, to compare participants' training and process operation habits, the PTM does not contain any explanations of why they must adhere to these instructions.

1. Adherence to Production Order Procedures (APOP)

   This variable measures participants' degree of adherence to the set of procedures written in the training manual regarding how to operate the system for a production order. It includes adherence to both the contents written in the procedures and performing the steps in the sequence they are arranged, with the exception of wait time procedures. Certain key steps that are likely to be disregarded or performed out of order were identified and the researcher gave a score on whether participants adhered in each of the 4 trials where a production order was operated. These scores were summed and a percentage of the total score was used for analysis.

2. Adherence to Changeover Procedures (ACOP)

   This variable measures participants' degree of adherence to procedures written in the training manual regarding how to operate the system for a process changeover. Similarly, it includes adherence to both the contents written in the procedures and performing the steps in the sequence they are arranged, with the exception of wait time procedures. Certain key steps that are likely to be disregarded or performed out of order were identified and the researcher gave a score on whether participants adhered in each of the 4 instances where a changeover was operated. These scores were summed and a percentage of the total score was used for analysis.

3. Adherence to Wait Times (AWT)

   This variable measures participants' degree of adherence to waiting for the full duration of the wait time indicated in the training manual. There was a total of 11 instances throughout the entire experiment where participants were asked to wait for a specified duration of time. Each instance was given a score on whether participants waited for at least the full duration of time indicated and a percentage of the total score was used for analysis.

Emergency Response

1. Emergency Response Score (ERS)

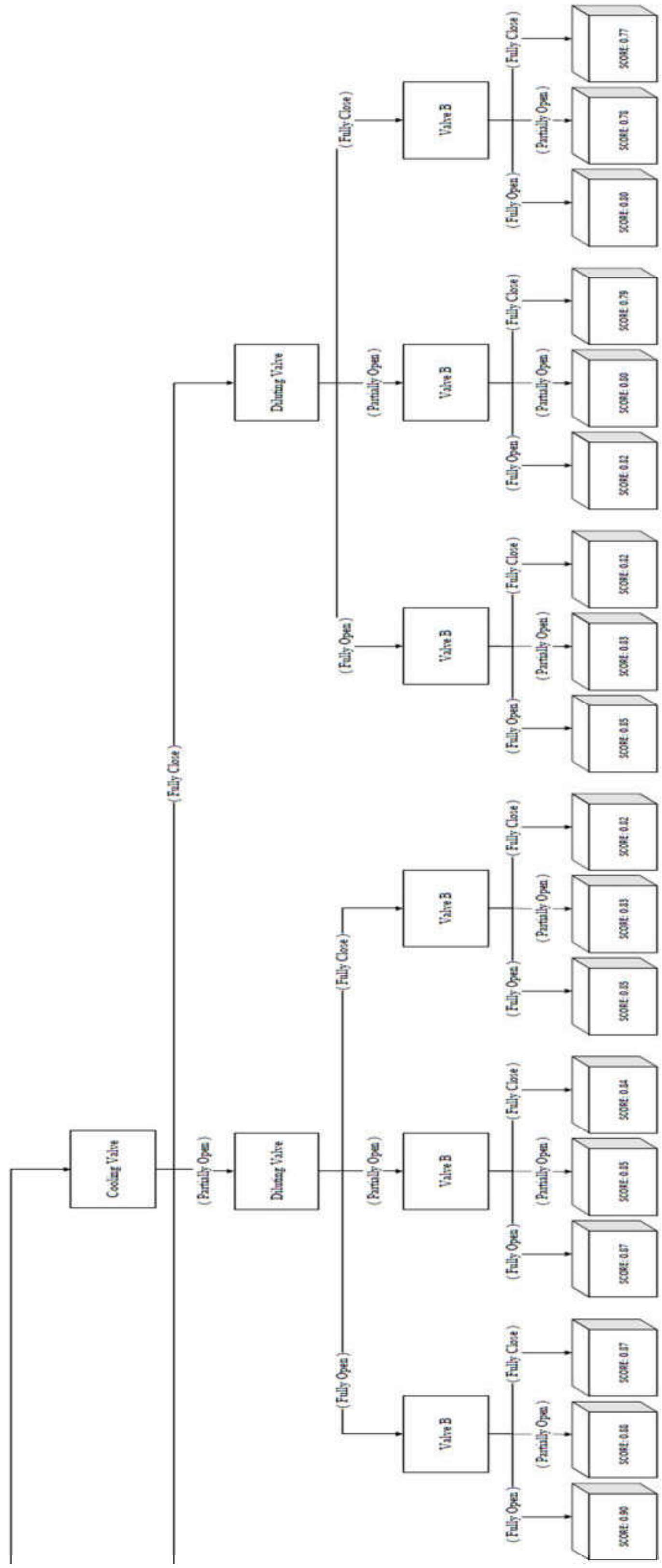
   In the second part of the emergency overheating scenario, participants are asked to disregard satisfying any operating criteria and parameters and to simply manipulate process controls in any way they deem fit to cool down the system as quickly as possible. Researchers then compiled a flow chart (Figure 7) of all possible combinations of process controls adjustments that could be made to the system and gave them each a score based on its appropriateness and significance to the scenario (Table 3). The final positioning of the 4 process control valves and inputs for the 2 chemical mass flow rates made participants to set the system in an ideal state that would maximize cooling at the reactor exit were recorded by the researcher through unobtrusive observations. This data was then rated and analyzed based on the rubric on its effectiveness at mitigating the incident.

Table 3: Emergency Response Scoring System

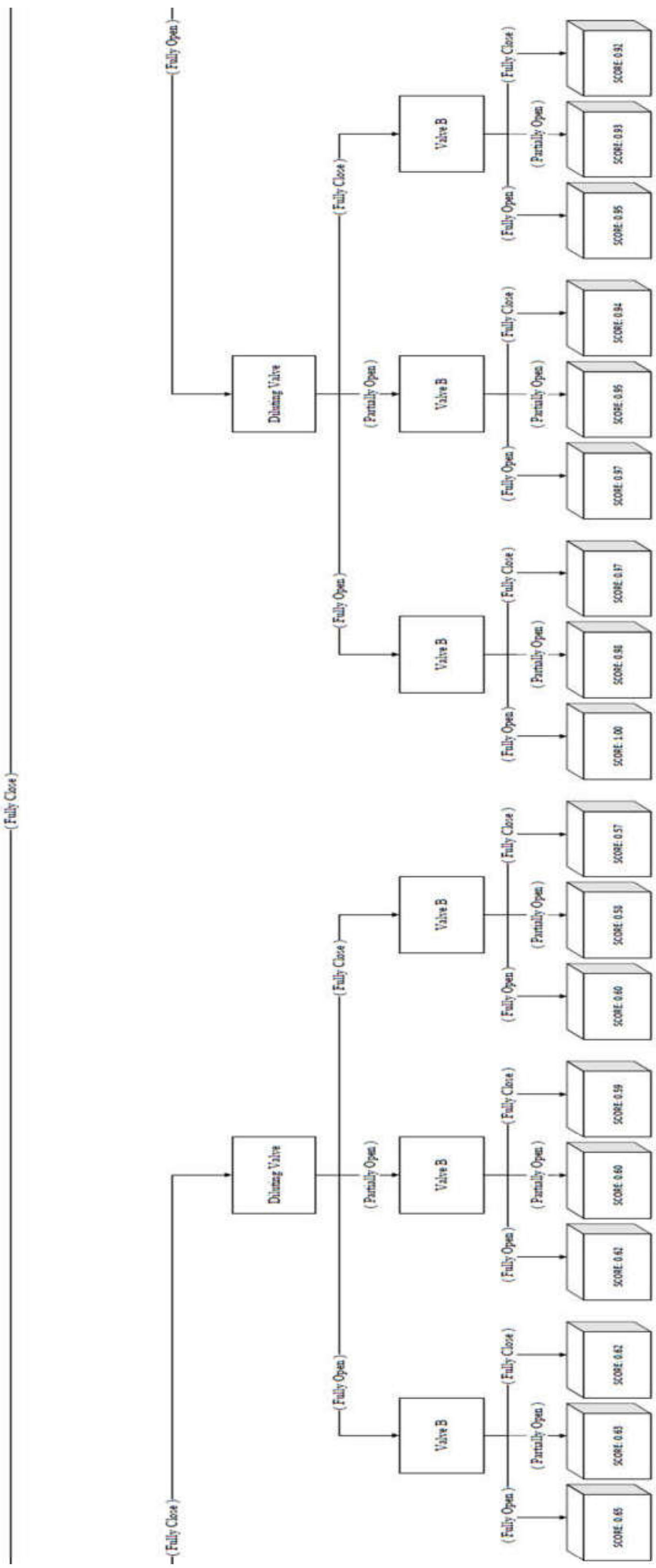
Process Control	Action	Score	Reason
Mass Flow Rates of Chemical A and B	Set = 0	0.35	This action is critical for halting the inflow of chemicals A and B to prevent further exothermic reaction.
	Set ≠ 0	0 FAIL	This action causes chemicals A and B to be continuously added into the system, thereby intensifying the exothermic reaction and further raising the temperature at the reactor exit.
Bypass Valve	Fully Open	0 FAIL	This action causes all water to bypass the system (inlet flow rate of 0 L/min) such that the temperature at the reactor exit is not cooled.
	Partially Open	0.10	This action enables a portion of the maximum possible inlet flow rate of water to flow through the system and cool the temperature at the reactor exit. The large deduction in score compared to having the bypass valve fully closed results in the significant impact opening it by any degree would have on the total amount of water that can be used to cool the system.
	Fully Close	0.30	This action enables the maximum inlet flow rate of water to flow through the system and cool the temperature at the reactor exit.
Cooling Valve	Fully Open	0.20	This action enables the maximum possible flow rate of cooling water at 5 °C to be used to cool the temperature at the reactor exit.
	Partially Open	0.10	This action enables a portion of the maximum possible flow rate of cooling water at 5 °C to be used to cool the temperature at the reactor exit. The reduction in score considers the significant impact this has on the amount of cooling water that can be used to directly cool the temperature at the reactor exit, while recognizing the alternate unrestricted stream A pathway that water could travel through to cool down the reactor using water at room temperature. In the latter case, the reactor exit is indirectly cooled by lowering the temperature of the purified water before it goes through the reactor exit,

			which also enables it to absorb heat from the overheating environment.
	Fully Close	0.05	This action causes all water to bypass the cooling stream such that no cooling water is used to directly cool down the temperature at the reactor exit. However, the non-zero score is due to water still being able to go through the unrestricted stream A pathway and cool down the reactor using water at room temperature, where it cools the purified water before it enters the reactor exit and absorbs heat from the overheating environment.
Diluting Valve	Fully Open	0.10	This action enables the maximum possible flow rate of water to enter the diluting stream, where it takes a shorter pathway and reaches the reactor faster, to cool down the reactor using water at room temperature. The reactor exit is indirectly cooled by lowering the temperature of the purified water before it goes through the reactor exit, which also enables it to absorb heat from the overheating environment.
	Partially Open	0.07	This action enables a portion of the maximum possible flow rate of water to enter the diluting stream to cool down the reactor using water at room temperature. The reactor exit is indirectly cooled by lowering the temperature of the purified water before it goes through the reactor exit, which also enables it to absorb heat from the overheating environment. The reduction in score is due to reduced flow through this ideal stream, excluding cooling stream, that has a diameter size that enables a considerable flow rate and a shorter pathway that enables water to reach the reactor faster.
	Fully Close	0.05	This action causes all water to bypass the diluting stream. However, the non-zero score is due to water still being able to go through the unrestricted stream A pathway and cool down the reactor using water at room temperature, where it cools the purified water before it enters

			the reactor exit and absorbs heat from the overheating environment.
Valve B	Fully Open	0.05	This action enables the maximum possible flow rate of water to enter stream B to cool down the reactor using water at room temperature. Although this stream has the lowest flow rate due to its small pipe diameter, it has the shortest pathway and enables water to reach the reactor the fastest. The reactor exit is indirectly cooled by lowering the temperature of the purified water before it goes through the reactor exit, which also enables it to absorb heat from the overheating environment.
	Partially Open	0.03	This action enables a portion of the maximum possible flow rate of water to enter stream B to cool down the reactor using water at room temperature. The reduction in score considers that although stream B is the shortest pathway that enables water to reach the reactor the fastest, the low flow rate due to its smaller pipe diameter would have a minimal effect on reducing the overall reactor temperature. Additionally, there is an alternate unrestricted stream A pathway that water could travel through to cool down the reactor using water at room temperature, where it cools the purified water before it enters the reactor exit and absorbs heat from the overheating environment.
	Fully Close	0.02	This action causes all water to bypass stream B. However, the non-zero score is due to water still being able to go through the unrestricted stream A pathway and cool down the reactor using water at room temperature, where it cools the purified water before it enters the reactor exit and absorbs heat from the overheating environment.



Cooling Valve
(Partially Open)
(Fully Close)
Diluting Valve
(Fully Open)
(Partially Open)
(Fully Close)
Valve B
SCORE: 0.90
SCORE: 0.88
SCORE: 0.87
SCORE: 0.87
SCORE: 0.85
SCORE: 0.84
SCORE: 0.85
SCORE: 0.83
SCORE: 0.82
SCORE: 0.85
SCORE: 0.83
SCORE: 0.82
SCORE: 0.82
SCORE: 0.80
SCORE: 0.79
SCORE: 0.80
SCORE: 0.78
SCORE: 0.77


(Fully Close)
(Fully Open)
(Fully Close)
Diluting Valve
Diluting Valve
(Fully Open)
(Partially Open)
(Fully Close)
Valve B
Valve B
Valve B
Valve B
Valve B
Valve B
(Fully Open)
(Partially Open)
(Fully Close)
SCORE: 0.92
SCORE: 0.93
SCORE: 0.95
SCORE: 0.84
SCORE: 0.95
SCORE: 0.97
SCORE: 0.97
SCORE: 0.98
SCORE: 1.00
SCORE: 0.57
SCORE: 0.58
SCORE: 0.60
SCORE: 0.59
SCORE: 0.60
SCORE: 0.62
SCORE: 0.62
SCORE: 0.63
SCORE: 0.65

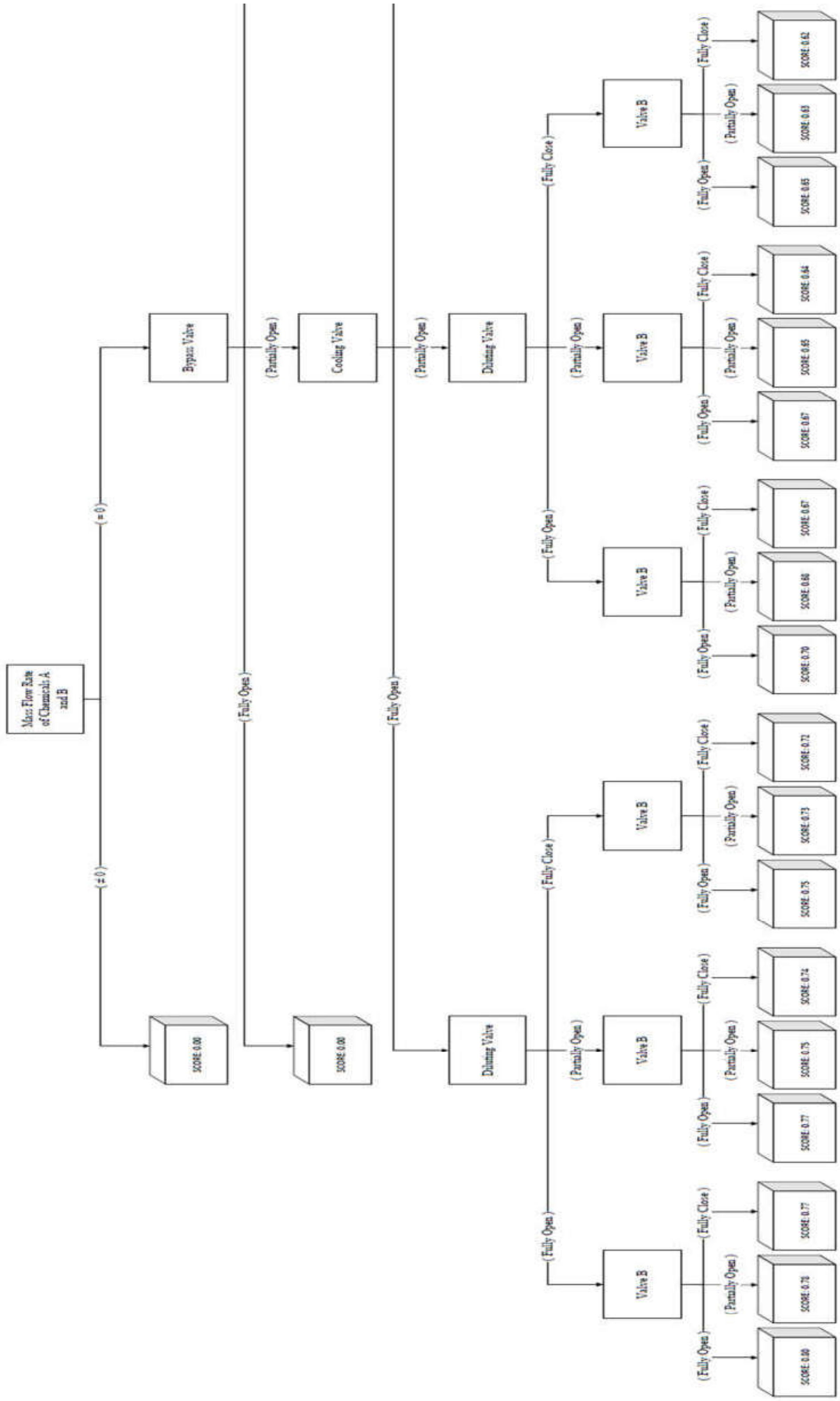


Figure 7: Emergency Response Combination of Process Controls

For the remaining factor of knowledge and retention, a mixed design ANOVA was used to analyze the dependent variable of questionnaire score. This ANOVA consists of 3 independent variables: 2 between-subject variables of manual (PTM and ETM) and education (CHE, ENG and FAC) and 1 within-subject variable of time to examine the difference in each participants' questionnaire score across 3 instances of time, namely before reading the training manual and operating the system (pre-test), immediately after operating the system (post-test), and approximately 2 weeks later (retention-test). Data was collected from participants' pre-test, post-test and retention-test scores on the questionnaire, which assesses them on the 3 categories of understanding of hydraulic pump system, technical and safety knowledge, and operation and scenario performance.

A 95% confidence interval was used to analyze the experimental results of this study. The data was interpreted by considering the results obtained from participants using a procedural training manual as a baseline, and comparing this to the degree to which results were found to be improved for participants using an explanatory manual.

Chapter 4
Results

At the beginning of the research study, each participant completed a pre-test questionnaire to assess their pre-existing understanding of concepts and skills related to operating the apparatus used in this experiment. A 2-way ANOVA analysis of these scores indicate that they are significantly impacted by both main effects of manual ($F(1, 54) = 10.581$, $p = 0.002$, $\eta^2 = 0.077$) and education ($F(2, 54) = 25.286$, $p < 0.001$, $\eta^2 = 0.367$), as well as the interaction effect between them ($F(2, 54) = 11.308$, $p < 0.001$, $\eta^2 = 0.164$). The eta-squared values indicate that education explains 36.7% of the variance in pre-test scores, while the interaction effect explains 16.4% of the variance. A simple contrast analysis indicates that CHE pre-test scores ($M = 0.223$, $SD = 0.131$) are significantly different from both ENG ($M = 0.060$, $SD = 0.059$, $p < 0.001$) and FAC ($M = 0.067$, $SD = 0.092$, $p < 0.001$). The post-hoc Bonferroni and REGWQ tests further confirm that while ENG ($p < 0.001$) and FAC ($p < 0.001$) had significantly lower pre-test scores compared to CHE, participants from both these educational backgrounds had similar pre-test scores ($p = 1.000$). Although manual (PTM: $M = 0.085$, $SD = 0.086$; ETM: $M = 0.117$, $SD = 0.137$) has a significant effect on pre-test scores, this was influenced by the interaction effect. Simple effects show that while manual assignment group factor had a significant effect on CHE pre-test scores ($p = 0.003$), it had no effect on those from both ENG ($p = 0.665$) and FAC ($p = 0.397$). Figure 8 further illustrates that in this experiment, where ENG participants randomly assigned an ETM ($M = 0.347$, $SD = 0.090$) happened to have or remember more background knowledge on this subject compared to those randomly assigned a PTM ($M = 0.130$, $SD = 0.056$), though both groups outperformed participants from other educational backgrounds. Since pre-existing understanding of relevant concepts and skills can impact participants' proficiency in each of the 4 factors, as hypothesized by researchers regarding the importance of understanding to process operation, pre-test questionnaire score was added as a covariant in the analysis of each dependent variable measured. Error bars have also been plotted on the graphs to indicate the range of a 95% confidence interval.

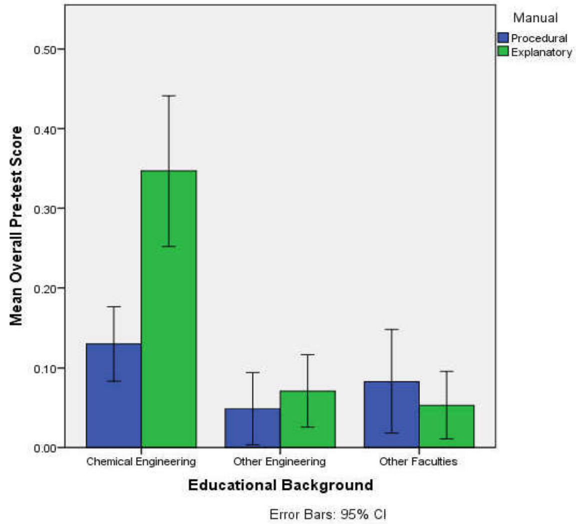


Figure 8: Average Pre-test Questionnaire Score [Range: 0.00 to 1.00]

4.1 Performance and Emergency Response

A 2-way ANOVA was conducted to examine the main effects of manual and education on each of the dependent variables examined within the factors of performance: time (Figure 9), PDWB (Figure 10), ZOBI (Figure 11), and ZRMSE (Figure 12), and of emergency response: ERS (Figure 13), while considering the co-variant of pre-test questionnaire score. Analysis of these results indicate that none of the main effects nor interaction effect were found to have any significance. Table 4 compiles a list of the ANOVA statistical results obtained on the significance of the between-subject effects for each dependent variable. Since the independent variables had no significant impact on the dependent variables below, the categorized groups segregating participants by manual and education can be combined into a single group. Table 5 lists the overall descriptive statistical results of mean (*M*) and standard deviation (*SD*) obtained for each dependent variable.

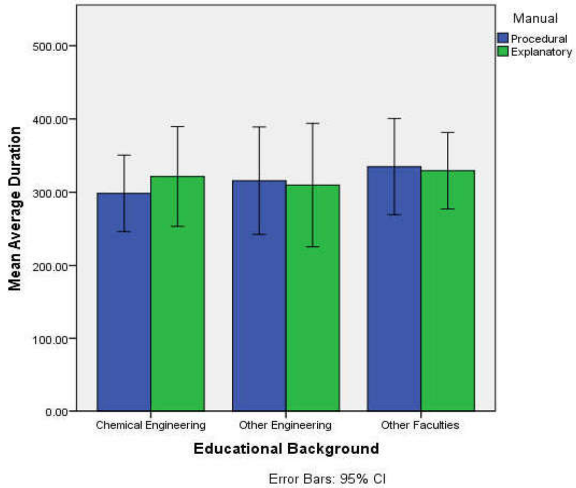


Figure 9: Average Performance Time (seconds)

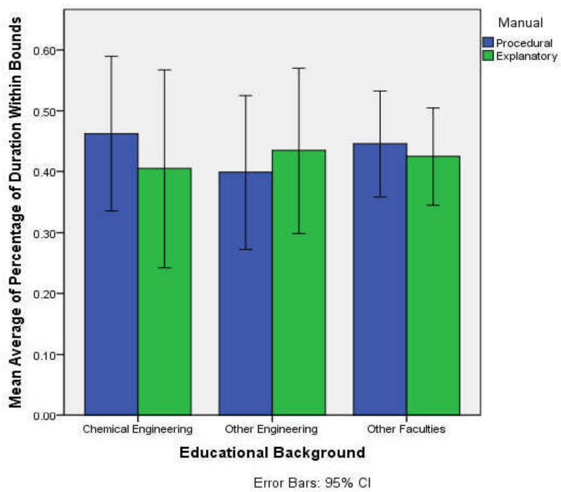


Figure 10: Average Performance PDWB [Range: 0.00 to 1.00]

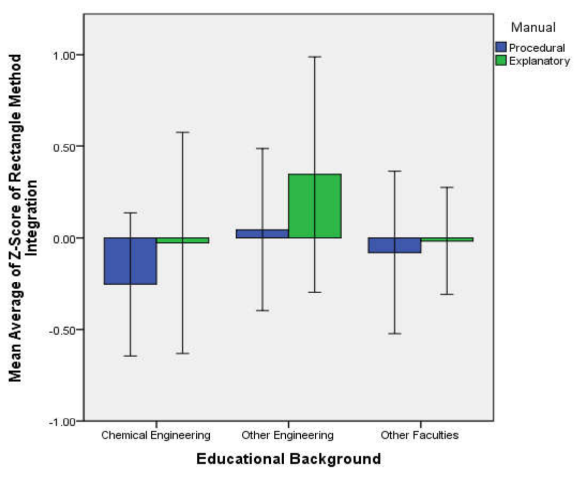


Figure 11: Average Performance ZOBI

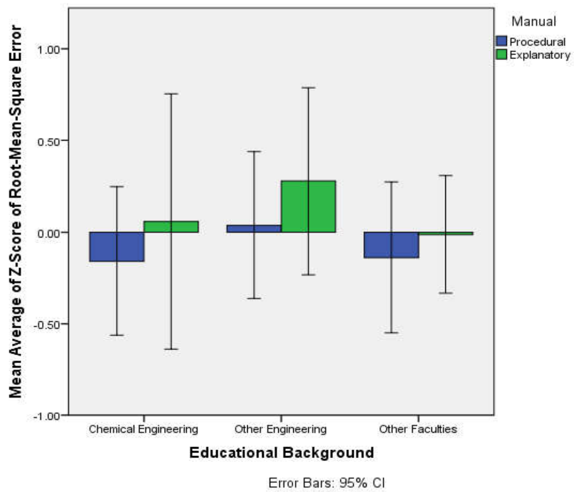


Figure 12: Average Performance ZRMSE

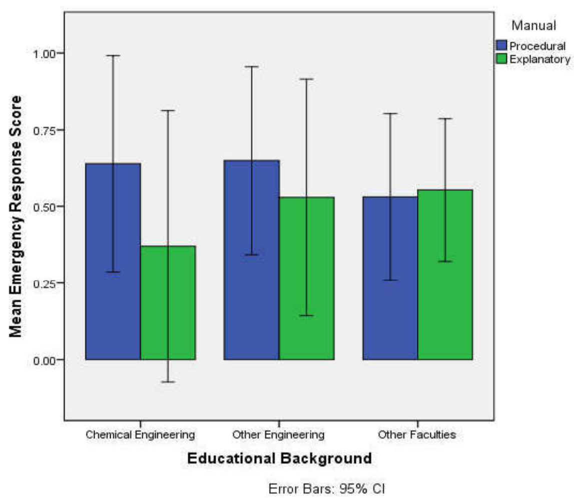


Figure 13: Average ERS [Range: 0.00 to 1.00]

Table 4: Between-Subject Effects for Performance and Emergency Response Variables

Independent Variables	Dependent Variable	Main/Interaction Effect	*df*	*F*	*p*	η^2
Manual + Education	Time	Manual	(1, 53)	0.331	0.567	0.006
		Education	(2, 53)	0.333	0.718	0.012
		Manual x Education	(2, 53)	0.496	0.612	0.018
Manual + Education	PDWB	Manual	(1, 53)	0.069	0.793	0.002
		Education	(2, 53)	0.089	0.915	0.003
		Manual x Education	(2, 53)	0.313	0.732	0.011

Manual + Education	ZOBI	Manual	(1, 53)	1.116	0.295	0.020
		Education	(2, 53)	0.976	0.384	0.035
		Manual x Education	(2, 53)	0.197	0.822	0.007
Manual + Education	ZRMSE	Manual	(1, 53)	1.219	0.275	0.022
		Education	(2, 53)	0.807	0.452	0.029
		Manual x Education	(2, 53)	0.058	0.943	0.002
Manual + Education	ERS	Manual	(1, 53)	1.025	0.316	0.019
		Education	(2, 53)	0.152	0.860	0.005
		Manual x Education	(2, 53)	0.469	0.628	0.017

Table 5: Descriptive Statistics for Performance and Emergency Response Variables

Independent Variables	**Dependent Variable**	***M***	***SD***
Manual + Education	Time	320.721	91.351
Manual + Education	PDWB	0.430	0.149
Manual + Education	ZOBI	< 0.000	0.630
Manual + Education	ZRMSE	- 0.001	0.596
Manual + Education	ERS	0.552	0.426

4.2 Adherence

Adherence to Production Order Procedures

A 2-way ANOVA analysis was conducted to examine the main effects of manual and education on participants' APOP, while considering the co-variant of pre-test questionnaire score. The results suggest that while manual has a significant effect on APOP ($F(1, 53) = 6.571$, $p = 0.013$, $\eta^2 = 0.099$), neither education ($F(2, 53) = 1.991$, $p = 0.147$, $\eta^2 = 0.060$) nor the interaction effect ($F(2, 53) = 1.368$, $p = 0.263$, $\eta^2 = 0.041$) were found to be significant. As seen in Figure 14, participants assigned to use an ETM ($M = 0.675$, $SD = 0.389$) were significantly found to have an overall higher APOP compared to those assigned a PTM ($M = 0.442$, $SD = 0.439$).

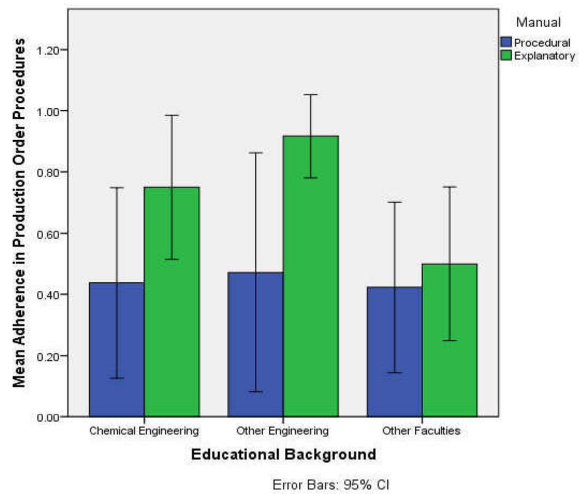


Figure 14: Average Adherence [Range: 0.00 to 1.00] to Production Order Procedures

Adherence to Changeover Procedures

A 2-way ANOVA analysis was conducted to examine the main effects of manual and education on participants' ACOP, while considering the co-variant of pre-test questionnaire score. Figure 15 illustrates a graph comparing participants' mean ACOP values between the 2 main effects. The results indicate that neither manual ($F(1, 53) = 0.816$, $p = 0.370$, $\eta^2 = 0.014$) nor education ($F(2, 53) = 1.127$, $p = 0.332$, $\eta^2 = 0.039$) nor the interaction effect between them ($F(2, 53) = 1.619$, $p = 0.208$, $\eta^2 = 0.055$) were found to have any significant effect on ACOP. Thus, considering all data to be from a single group, participants had an overall mean ACOP of 0.971 with a standard deviation of 0.093.

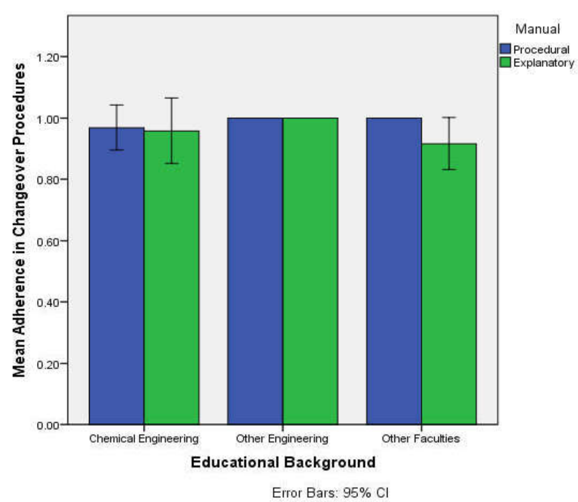


Figure 15: Average Adherence [Range: 0.00 to 1.00] to Changeover Procedures

Table 6 lists the top 9 reasons mentioned by participants explaining why they decided to adhere or to not adhere to production order and changeover procedures in general. The reasons in the table that are indented and in italics are not included as one of the top 9 reasons but have been included for qualitative purposes due to its similarity and association with the reason directly above it in regular font. The numbers represent the percentage of participants present within a certain category that specified a certain reason to be the rational behind why they did or did not adhere to procedures during the experiment and each participant could list an unlimited number of reasons involved.

From this table, it can be seen that 2 of the top 3 reasons are explanations of why participants chose to adhere to the procedure. The number 1 reason given by 42% of all participants stated they adhered simply because that was what they were instructed to do in the training manual. A related reason that it is important to adhere to the procedures because the author knows this system best and must have had a reason for including it in the manual was reported by 10% of all participants, while another related reason reported by 2% of all participants was that the purpose for adhering was repeated several times throughout the manual and enabled participants to recognize its importance. The number 3 reason on the list was given by 22% of all participants and they adhered either because the reason in the manual convinced them to do so or because they thought there must be some sort of reason why a certain step was included in the manual and so it would be important to adhere to it. On the contrary, the remaining top 3 reasons is an explanation of why participants chose not to adhere to the procedure. This number 2 reason on the list by 28% of all participants is that it was an accident that they failed to adhere and it was not done on purpose.

Table 6: Top Reasons by Participants for or Against APOP and ACOP

Reason For/Against APOP and ACOP	**PTM**			***Total PTM***	**ETM**			***Total ETM***	***Total***
	CHE	**ENG**	**FAC**		**CHE**	**ENG**	**FAC**		
Reasons For Adhering									
instructed to do so in manual	0.13	0.11	0.38	***0.23***	0.83	0.89	0.33	***0.60***	***0.42***
author knows system best and included this step because it is important to the overall process so it is necessary	0.00	0.00	0.08	***0.03***	0.33	0.22	0.07	***0.17***	***0.10***
repeated several times in the inserted notes so it must be important	0.00	0.00	0.00	***0.00***	0.00	0.00	0.07	***0.03***	***0.02***

reason in manual was convincing/ there must be a reason why it was included in manual so it is important	0.25	0.11	0.00	***0.10***	0.33	0.44	0.27	***0.33***	***0.22***
did not know enough to make own judgements about operation	0.00	0.11	0.15	***0.10***	0.17	0.33	0.07	***0.17***	***0.13***
unsure if system would still operate properly if did not adhere	0.13	0.11	0.08	***0.10***	0.17	0.00	0.13	***0.10***	***0.10***
Reasons Against Adhering									
accidentally failed to adhere; not on purpose	0.25	0.22	0.23	***0.23***	0.33	0.11	0.47	***0.33***	***0.28***
did not remember exact instructions/sequences in manual while operating	0.13	0.11	0.08	***0.10***	0.00	0.00	0.40	***0.20***	***0.15***
did not think it was important to follow exactly as long as end goal was met (despite reason)	0.38	0.00	0.23	***0.20***	0.17	0.00	0.13	***0.10***	***0.15***
thought it was easier to operate using own method	0.00	0.11	0.38	***0.20***	0.17	0.00	0.13	***0.10***	***0.15***
thought own method was better than those in manual	0.13	0.44	0.15	***0.23***	0.00	0.00	0.00	***0.00***	***0.12***

Table 7 lists the top 9 reasons mentioned by participants explaining why they decided to adhere or to not adhere to the full duration of the wait times indicated in the training manual. The most frequent answer by 35% of all participants was that they adhered simply because that was what was written in the manual. A related reason mentioned by 10% of participants stated that it is important to adhere to the procedures because the author knows this system best and must have had a reason for including it in the manual. However, the remaining 2 responses of the top 3 reasons both explained why participants chose not to adhere. The second most frequent answer by 28% of all participants was that they felt it was only necessary to wait until the system reached steady state, while the third most frequent answer by 25% of all participants was that they did not think it was important to wait either at all or for the full duration indicated in the manual, despite the reason given to ETM participants. A related reason to the number 3 reason the list was that 10% of ETM participants did not even read the reasons and naturally did not know its importance, while 13% of CHE participants using a PTM felt it was unnecessary to adhere because it was not a criterion.

Table 7: Top Reasons by Participants for or Against AWT

Reason For/Against AWT	PTM			*Total PTM*	ETM			*Total ETM*	*Total*
	CHE	ENG	FAC		CHE	ENG	FAC		
Reasons For Adhering									
instructed to do so in manual	0.25	0.33	0.38	***0.33***	0.33	0.44	0.33	***0.37***	***0.35***
author knows system best and included this step because it is important to the overall process so it is necessary	0.13	0.11	0.08	***0.10***	0.17	0.00	0.13	***0.10***	***0.10***
reason in manual was convincing/ there must be a reason why it was included in manual so it is important	0.13	0.11	0.15	***0.13***	0.50	0.22	0.27	***0.30***	***0.22***
understand importance of waiting full duration on overall process	0.00	0.22	0.15	***0.13***	0.33	0.22	0.00	***0.13***	***0.13***
needed to stabilize the system at steady state	0.25	0.11	0.08	***0.13***	0.00	0.00	0.13	***0.07***	***0.10***
Reasons Against Adhering									
felt it was only necessary to wait until steady state	0.13	0.33	0.31	***0.27***	0.50	0.22	0.27	***0.30***	***0.28***
did not think it was important to wait at all/ full duration indicated (despite reason)	0.38	0.11	0.15	***0.20***	0.33	0.44	0.20	***0.30***	***0.25***
did not read reason why needed to adhere so did not know its importance	0.00	0.00	0.00	***0.00***	0.17	0.00	0.13	***0.10***	***0.05***
not a criterion so it is okay not to adhere	0.13	0.00	0.00	***0.03***	0.00	0.00	0.00	***0.00***	***0.02***
this is just an experiment so did not think it was necessary	0.38	0.33	0.23	***0.30***	0.17	0.22	0.13	***0.17***	***0.23***
would have adhered if actually operating in a production setting	0.00	0.00	0.08	***0.03***	0.00	0.11	0.07	***0.07***	***0.05***
did not pay attention to time so just waited approximately	0.13	0.33	0.15	***0.20***	0.17	0.00	0.33	***0.20***	***0.20***
there was no reaction from manager when did not wait full duration so thought it was unnecessary	0.13	0.00	0.15	***0.10***	0.17	0.11	0.13	***0.13***	***0.12***
missed this step when reading instructions so did not know needed to wait	0.38	0.11	0.08	***0.17***	0.17	0.00	0.00	***0.03***	***0.10***

Adherence to Wait Times

A 2-way ANOVA analysis was conducted to examine the main effects of manual and education on participants' AWT, while considering the co-variant of pre-test questionnaire score. Figure 16 illustrates a graph comparing participants' mean AWT values between the 2 main effects. The results indicate that neither manual ($F(1, 53) = 0.355$, $p = 0.554$, $\eta^2 = 0.006$) nor education ($F(2, 53) = 0.526$, $p = 0.594$, $\eta^2 = 0.019$) nor the interaction effect between them ($F(2, 53) = 0.399$, $p = 0.673$, $\eta^2 = 0.014$) were found to have any significant effect on AWT. Thus, considering all data to be from a single group, participants had an overall mean AWT of 0.621 with a standard deviation of 0.292.

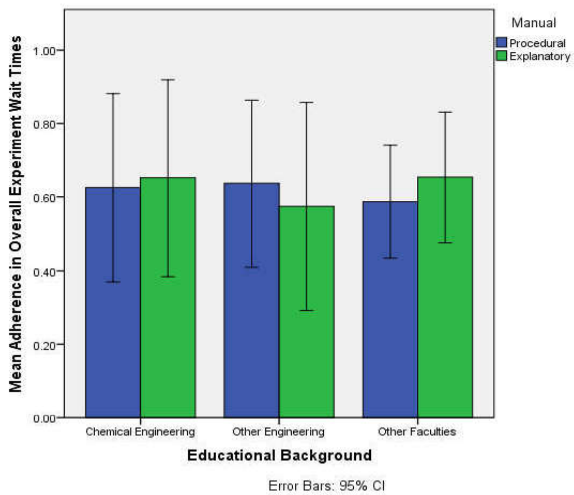


Figure 16: Average Adherence [Range: 0.00 to 1.00] to Wait Times

4.3 Knowledge and Retention

A mixed design ANOVA was conducted to examine the between-subject effects of manual and education and the within-subject effect of time on participants' questionnaire score. Figure 17 illustrates comparison graphs of participants' mean questionnaire scores between the 3 main effects of manual, education and time. Table 8 compiles a list of the ANOVA statistical results obtained on the significance of the within-subject and between-subject effects for questionnaire score. The within-subject analysis indicates that the main effect of time, the 2-way interaction effects between time and manual and between time and education, as well as the 3-way interaction effect between time, manual and education all have a significant impact on score. On the other hand, the between-subject analysis indicates that while education has a significant impact on score, neither manual nor the 2-way interaction effect between manual and education have any significance. Table 9 lists the overall descriptive statistical results of mean (*M*) and standard deviation (*SD*) obtained for questionnaire score.

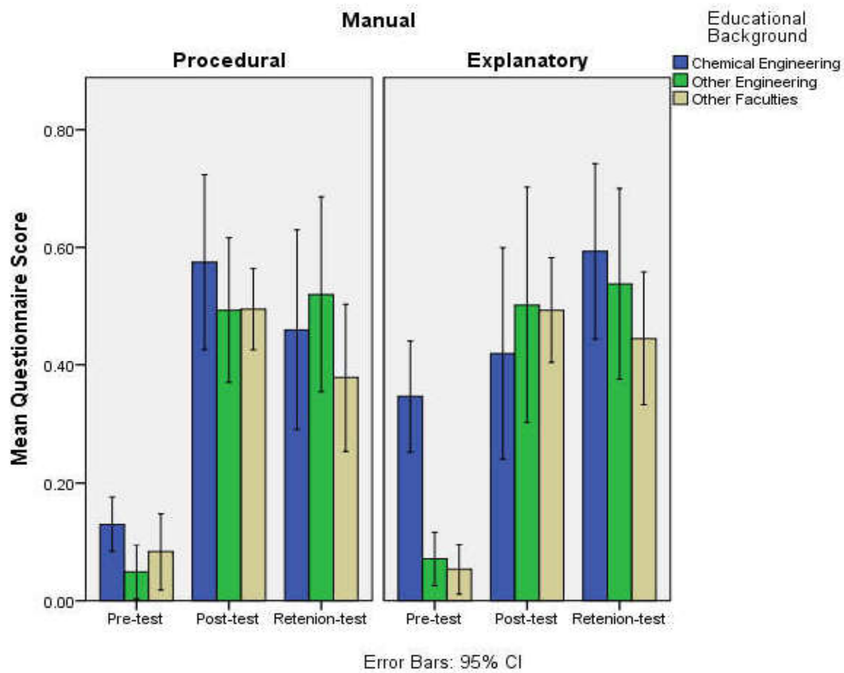


Figure 17: Average Questionnaire Score [Range: 0.00 to 1.00]

Table 8: Between-Subject and Within-Subject Effects on Questionnaire Score

Main/Interaction Effect	*df*	*F*	*p*	η^2
Within-Subject Effects				
Time	(2, 108)	129.162	< 0.000	0.650
Time x Manual	(2, 108)	3.417	0.036	0.017
Time x Education	(4, 108)	3.378	0.012	0.034
Time x Manual x Education	(4, 108)	2.737	0.032	0.028
Between-Subject Effects				
Manual	(1, 54)	1.022	0.317	0.016
Education	(2, 54)	3.307	0.044	0.106
Manual x Education	(2, 54)	0.274	0.761	0.009

Table 9: Descriptive Statistics on Questionnaire Score

	CHE	ENG	FAC	*Total*
		Pre-test Score		
PTM	*M* = 0.130 *SD* = 0.056	*M* = 0.049 *SD* = 0.059	*M* = 0.083 *SD* = 0.108	*M* = 0.085 *SD* = 0.086
ETM	*M* = 0.347 *SD* = 0.090	*M* = 0.071 *SD* = 0.059	*M* = 0.053 *SD* = 0.077	*M* = 0.117 *SD* = 0.137
Total	*M* = 0.223 *SD* = 0.131	*M* = 0.060 *SD* = 0.059	*M* = 0.067 *SD* = 0.092	*M* = 0.101 *SD* = 0.115
		Post-test Score		
PTM	*M* = 0.575 *SD* = 0.178	*M* = 0.493 *SD* = 0.160	*M* = 0.495 *SD* = 0.114	*M* = 0.516 *SD* = 0.146
ETM	*M* = 0.420 *SD* = 0.171	*M* = 0.502 *SD* = 0.260	*M* = 0.493 *SD* = 0.161	*M* = 0.481 *SD* = 0.193
Total	*M* = 0.509 *SD* = 0.186	*M* = 0.498 *SD* = 0.210	*M* = 0.494 *SD* = 0.139	*M* = 0.499 *SD* = 0.171
		Retention-test Score		
PTM	*M* = 0.460 *SD* = 0.203	*M* = 0.520 *SD* = 0.215	*M* = 0.379 *SD* = 0.207	*M* = 0.443 *SD* = 0.210
ETM	*M* = 0.593 *SD* = 0.142	*M* = 0.538 *SD* = 0.211	*M* = 0.445 *SD* = 0.204	*M* = 0.503 *SD* = 0.199
Total	*M* = 0.517 *SD* = 0.186	*M* = 0.529 *SD* = 0.207	*M* = 0.414 *SD* = 0.204	*M* = 0.473 *SD* = 0.205

The results of a simple contrast performed on the within-subject effects and the between-subject effect of education are indicated in Table 10. Interestingly, while simple contrast suggests a significant difference in education between CHE and FAC, the Bonferroni post-hoc test (p = 0.053) suggested otherwise. As this p-value is very close to being significant and Bonferroni is considered a more conservative test, an additional Tukey HSD post-hoc test that is more liberal was also conducted. Similar to simple contrast, Tukey HSD also suggests a significant difference (p = 0.046).

Table 10: Simple Contrasts on Between-Subject and Within-Subject Effects on Score

Main/Interaction Effect	Comparison	*p*
	Within-Subject Effect	
Time	Pre-test vs. Post-test	< 0.000
	Post-test vs. Retention-test	0.774
Time x Manual	Pre-test vs. Post-test	0.032
	Post-test vs. Retention-test	0.021
Time x Education	Pre-test vs. Post-test	0.026
	Post-test vs. Retention-test	0.081
Time x Manual x Education	Pre-test vs. Post-test	0.011
	Post-test vs. Retention-test	0.109
	Between-Subject Effect	
Education	CHE vs. ENG	0.155
	CHE vs. FAC	0.013

Chapter 5
Discussion

5.1 Performance

Contrary to the researchers' hypothesis, neither manual nor education had a significant effect on participants' performance in terms of time, PDWB, ZOBI and ZRMSE. A possible explanation for this is that the PTM was sufficient to enable participants to learn how to properly operate the system, such that the additional explanations in ETM did not result in any notable improvement in their performance. This result is in favor of the current training manuals used by industrial companies since simply using procedural-based instructions is sufficient for training employees. It also indicates that even if employees do not fully understand the relevant concepts underlying the operation, they are still able to perform at a reasonable standard comparable to those who have been provided training in this area.

Although CHE and ENG participants may be more familiar with manipulating process controls compared to FAC participants, the system and process operation were specifically designed to be slightly more complicated to create a scenario where all participants needed to learn a new task. Through this learning process, CHE and ENG participants' greater understanding of relevant concepts was not found to enable them to faster and better apply head knowledge to hands-on operation since they are also learning how to apply what they know to this new environment. Thus, the reason these slight advantages that CHE and ENG participants have over FAC participants are insufficient to causing any significant difference in performance may be due to all participants having a similar starting point in learning a new system and applying what they have learned. Research analysis of a 1993 National Survey of College Graduates shows that 55% of workers report being in a job where their field of study is closely related to their field of work. Especially for degrees that emphasize more on skills related to a specific occupation, such as engineering, there is a lower prevalence of mismatch between one's educational background and the field of their current occupation. [55] However, the results of this experiment suggest that educational background does significantly affect operation time and accuracy performance in this type of operations with explicit manual and standard procedures. Most companies operate processes that are highly specialized within their field, whereas universities tend to teach students very generalized concepts that only provides them with a brief understanding of a wide variety of fields. It is only during the company's employee training session where these engineering graduates really encounter and learn to operate technical system, meaning their starting point in this learning process is approximately the same as those from a non-engineering specialization. Another research study by Allen and Van der Velden found that educational mismatch is not a condition that necessarily effects skill mismatch. While educational mismatch has a strong effect on wage, only a small proportion is accounted for by skill mismatch. However, after controlling for job quality, skill mismatch was found to have a strong effect on employee job satisfaction, whereas educational mismatch has no effect on it. [56] These findings indicate that an employee's educational background does not necessarily dictate their skill sets and so, a more technical background did not enable CHE or ENG participants to significantly learn faster than FAC participants. Thus, since all participants in this experiment had a similar starting point, they also progressed through the training at similar speeds. This suggests that companies should focus more on the skills that new employees can bring to the team when hiring, rather than just on their educational background, as it enables a more sensible distribution of wage based on what employees can do [56] and may also have a greater effect on their performance compared to education. The ability to apply their knowledge and skills to their current job further enables employees to feel greater satisfaction in their current job, benefiting both the company and the employee [56].

5.2 Adherence

Adherence to Procedures

In line with the researchers' hypothesis, manual was found to have a significant effect on APOP in this experiment, where participants using an ETM had a significantly higher APOP compared to those using a PTM. This confirms that when employees are provided with a reason why they need to follow to certain procedural steps or sequences, they are more likely to adhere than if they do not understand the importance for adhering and the consequence of not adhering. This has significant implications when creating training sessions as it points out that employees do not always strictly follow the procedures given to them, even when training for the first time on a new system. It stresses the importance of clearly and thoroughly explaining to new operators the purpose for performing certain steps that are essential to execute and strictly following sequences that must be complete in a certain order regardless of how intuitive they may seem. Employees tend to have a greater degree of adherence to production order procedures due to its complexity. However, at the same time, it may cause unfamiliar operators to feel overwhelmed as they lack the experience and are ignorant of the necessity for certain procedures and its impact on the overall process, leading them to attempt to simplify the process or to create their own methodologies for operation that make more sense to them while trying to understand the system.

Contrary to the researchers' hypothesis, manual had no significance effect on ACOP in this experiment and all participants were found to have similar high degrees of ACOP spread across a small standard deviation. A likely reason for the lack of effect of manual on ACOP is that the procedures to operate a changeover are too straightforward and easy to execute that majority of the participants simply operated in accordance with the procedures without any further thought. This indicates that simply providing participants with PTM instructions is sufficient for achieving the purpose of this simple task, such that the inclusion of additional explanations in the ETM were not able to significantly motivate them to adhere to an even greater degree. This applies that while the procedures of complex tasks should be thoroughly explained so employees understand the necessity for adhering to them, simple and straightforward procedures do not require explanations as employees will likely adhere to them directly.

From Table 6, the top explanations participants gave for choosing to adhere to procedures was because they were instructed to do so in the manual and either the reason convinced them or they believe there must be a reason why the step was included in the procedure. In all these incidences, these reasons were reported more frequently by participant using an ETM compared to those using a PTM, likely due to the additional explanations which guided them to adhere. CHE and ENG participants were also found to have stated these reasons more often amongst those using an ETM, likely due to having a greater understanding of the terminologies used and rationales for adhering. Again, this highlights the importance of properly ensuring new employees understand the purpose underlying the procedures and sequences that must be performed in a certain manner, such that they know what they must adhere to.

Contrary to the researchers' hypotheses, education was found to have no significant effect on either APOP or ACOP in this experiment. This means that an employee's educational background is not indicative of their degree of adherence to procedures in general. Although certain majors educate students on the importance of following protocols for quality assurance and process safety, it does not necessarily lead to a greater degree of adherence due to a number of other factors in play. This stresses the need to remind all employees of the importance or reasoning for adhering rather than just assuming they should already know due to having educational background that emphasizes accuracy and precision. From Table 6, the most common explanation of why participants chose not to adhere to the procedures was that it was an accident and not done on purpose. This reasoning was approximately the same for both PTM and ETM participants and across the various educational backgrounds. This indicates that when training new employees, it would be beneficial to grab their attention by boldly highlight crucial procedural steps or sequences that must be adhered, as well as to constantly remind then through alerts or a trainer what they have missed or done incorrectly.

Adherence to Wait Times

Contrary to the researchers' hypothesis neither manual nor education had a significant effect on participants' AWT. All participants were found to have an overall above average AWT, meaning that the additional explanations in the ETM had no effect on improving AWT compared to participants using a PTM. Although an above average AWT is general not a bad score, considering that this wait time is a crucial step to the process, as is the case in this experiment, simply using a PTM would be insufficient for achieving the purpose of adherence.

From Table 7, participants that adhered to the full duration of the indicated wait time most commonly reported adhering because it was written in the manual. On the contrary, the most common reason why some participants chose not to adhere for the full duration of wait time because they felt it was only necessary to wait until the system reached steady state, which is the desired end state of the system for the task. This reasoning was approximately mentioned at the same frequency for both PTM and ETM participants, with CHE participants using an ETM stating this reason considerably more. This may be due to their past experience using similar systems, where they could progress to the next step immediately after steady state was reached, which overshadowed the reason in the ETM explaining why they should adhere for the full wait time. Another reason was that participants chose not to adhere because they did not think it was important to wait either at all or for the full duration indicated in the manual, despite the reason given for ETM participants. Unexpectedly, this reasoning was given by a greater percentage of ETM participants compared to PTM, probably because the reasoning failed to convince them or it made them feel it was not a valid reason. Interestingly, 23% of all participants stated they did not adhere because this was only an experiment to them so it was not important to do so. As expected, PTM participants named this reason more often than ETM, while it was approximately the same across educational background, probably due to the lack of explanations regarding their influence on the overall process. This finding could be crucial to training programs as it could signify that new employees are not taking this simulated training seriously as it is not real. As a prelude to operating on the actual production process, it is essential that operators are properly trained as they will not only affect product quality but also the system itself. Thus, companies are recommended to create realistic training programs that simulate actual operation settings to motivate new employees to learn.

5.3 Emergency Response

Contrary to the researchers' hypothesis, all participants has an overall average ERS as neither manual nor education had a significant effect on participants' ERS. In this experiment, all participants were given an identical section in the manual that introduced them to the overheating scenario and gave brief hints of how it could be brought under control. Participants were expected to use the knowledge they learned from the manual and their experience operating the system to appropriately handle this emergency scenario. This task was designed to assess whether participants adequately understand the operation process and the overall system as a whole. Some essential factors to controlling this emergency, such as familiarity with stream pathways and valve manipulation, are the same factors that determine a participant's level of performance. Thus, since operation time and accuracy performance was found to be neither influenced by manual nor education background (see Section 5.1), it extends that emergency response was similarly not influenced. This indicates that simply training employees to operate the system or educating them on the underlying concepts involved in the process is not be sufficient to enable employees to know how to effectively and efficiently respond in an emergency scenario. Companies need to conduct emergency response training, ideally also covering the various stages of the emergency, to properly guide employees on what they can do to prevent the emergency in its early stages or to mitigate its severity once it starts becomes unpreventable.

5.4 Knowledge and Retention

Most distinctly, a comparison of the 2 graphs in Figure 17 reveals an increase in score before and after participants read the training manual and operated the system. For all participants, their post-test score is considerably higher than their pre-test score, validating the usefulness of both manuals on increasing participants' understanding of the system and process operation. There is also no significant difference found between participants' post-test and retention-test scores, which is a positive sign that even after approximately 2 weeks, participants were still able to retain the same level of performance on the questionnaire. Through the improvement of these results, the importance of providing employees with adequate guidance during training is manifest.

In support of the researchers' hypothesis, the between-subject main effect of education was found to have a significant impact on score in this experiment. This effect is attributed to the fact that overall, CHE outperformed FAC participants across all conditions. This is probably due to CHE participants having likely learned these concepts before, leading the manual to serve as a reminder to refresh their memory, and being more familiar with the terminologies used, enabling them to better understand the materials presented and how it relates to the overall system. Yet, despite this significant effect, it surprisingly did not translate into similar scores for the factors of performance and emergency response. These results suggest that there is a difference between knowing something and doing something. Although application does require some degree of head knowledge, in the end, the purpose is to produce a quality product that will satisfy customers. Thus, companies are encouraged to train new employees in a way that teaches them to consciously apply knowledge into operation, such that even in the event of a previously unforeseen incident, they can use the knowledge they learned to develop a suitable procedure that can mitigate its effects.

Additionally, while all the within-subject effects were found to have a significant impact on score in this experiment, neither the between-subject main effect of manual nor the interaction effect between manual and education had a significant impact on score. From Figure 17, the most plausible justification for these different significant and non-significant effects is the significantly higher pre-test score of CHE participants assigned an ETM. This is because with the exception of this group of participants, all other participants follow a similar trend in their questionnaire score regardless of condition.

5.5 Implications

The results of this research study have significant implications for both the research field and the industrial sector. First and foremost, this research stresses the importance of training. For safety purposes and for the benefit of the company, it is essential to create suitable training programs that will enable operators to be adequately prepared to respond effectively and efficiently to both normal and abnormal situations. The research topic explored in this study is the first of its kind to examine the importance of understanding and its impact on industrial processes. These findings are expected to spark interest in other researchers on the potential of this field and the significant impact it could bring about in improving operator training programs. They also give companies an idea of the degree of effect understanding the underlying concepts relevant to the process could have on operator's performance, adherence, emergency response, and knowledge and retention.

These results will also contribute to the development of better training programs and more suitable training manuals. In support of the recommendation given by many researchers in previous studies, participation in the training program, regardless of manual assigned, was shown to significantly increase operator understanding of the system and process operation. Although CHE outscored FAC participants, all participants had similar performance and emergency response, indicating a difference between knowing and applying. This suggests a need to focus training session on not only providing operators with relevant knowledge on the process and training them to operate the system, but also providing the link in-between by teaching them to apply head knowledge to operation, which will enable them to be prepared and know how to come up with an appropriate response to any situation. Continuing the use of PTM in companies, which is similar to the training manuals currently being used in the industry, is acceptable as it was shown to be sufficient in enabling operators to perform at a standard comparable to those using an ETM, who were provided with explanations that were supposed to help them operate faster and more accurately due to better understand of the process. However, results recommend that companies switch to using ETM instead as it is important to add sufficient explanations to procedures to at least inform employees of the reasons for adhering and consequences behind failing to adhere. When composing training manuals, critical steps and complex tasks with procedures that must be followed require explanations to ensure operators clearly understand the reason for completing certain steps and the necessity to follow these procedures in the manner they are written. On the contrary, simple tasks do not necessarily require explanations as the procedures are simplified enough that employees will directly execute them accordingly. It is important to note that a portion of the participants reported that they chose not to adhere because this was only an experiment. This implies that some employees may not take the training session seriously either since it is only a simulation. Thus, this stresses the need for adding realism to training sessions so employees understand how it relates to their own operation and see value in this training

5.6 Limitations

The results obtained in this experiment are by no means conclusive and simply report the findings from this particular research study. There are many areas in this study that could still be improved to better and more stringently assess these factors. These limitations mainly derived from the lack of collaboration with industrial companies. The initial purpose of performing this experiment within a university setting was to get a general sense of the effect of understanding on each of the 4 factors prior to collaborating with companies to repeat this study or a revised version in an industrial setting. However, data analysis suggest that this lack of realism may have a more significant impact on participants' results than initially expected when learning theoretical concepts for operation of an industrial process. Of the 60 participants that volunteered for this experiment, 23% chose not to adhere because they only considered this to be an experiment so it was not important. Also, since this experiment was performed within the university and participants varied in their level of prior experience and safety knowledge, the apparatus was designed with an emphasis on safety such that the system would not easily break or cause an accident due to mishandling of equipment. Thus, no chemicals other than water at room-temperature was used to prevent chemical hazards and large equipment such as reactors, tanks and the spray chamber were simply represented by paper diagrams due to lack of space and to prevent accidents from improper adjustments of system controls, which may have further prevented the realism of the simulation. Although 42% of participants reported following the procedures in the manual because they trusted its content and that the writer was an expert familiarized with the system and how it should best be operated, 63% deviated from the procedures at least once and 75% choose not to wait for the full duration of the wait time specified at least once because they thought it was unimportant or unnecessary to be followed exactly. Furthermore, due to the design of the 2-part emergency scenario, the reactor must be simulated to continuously remain in an overheating state until participants complete the second part. Since the overheating alarm was constantly on and there was no temperature indicator, simulating an environment where participants were not given feedback but had to use their own knowledge to make appropriate judgements to bring the system under control, several participants reported being confused during the emergency scenario and questioned the lack of response from the control system, leading them to question their adjustment of system controls and if they were making correct decisions.

Another deficiency in this research study was that participants were expected to complete the entire experiment, with the exception of the retention portion of the study, in one sitting. Although researchers did not rush the participants and allowed them as much time as they needed to read the training manual and operate the system, these 2 portions of the experiment generally only lasted between 1 to 2 hours in duration which is very short compared to the amount of time an average production worker trainee spends on training. Even though participants were only required to complete several trials of a small, non-intuitive task in this experiment, 1 to 2 hours of self-training and experimentation was not sufficient for them to fully master the operation of the system and understand its underlying concepts. This was especially the case for participants assigned the explanatory training manual, which introduced them to the key aspects of concepts important to process operation and their effects on the essential parameters, this manual contained a large amount of information which they needed to recall or learn within a short period of time and then apply. Additionally, since this experiment was not performed within an industrial setting and with actual production workers, participants may have lacked the motivation to seriously read over the training manual with the goal of fully understanding the documented concepts and applying this knowledge during process operation. Unlike actual production workers who most likely are motivated and will put in the extra effort because they need to learn this knowledge for work and will be applying these skills on a day-to-day basis, this experiment is likely the only time most participants will come into contact with or use the fluid mechanic concepts and system operation skills they are trained to perform in this research study. Thus, as evident by the large percentage of participants (a fourth of the total participants) who did not take this research study seriously due to simply regarding it as an experiment or simulation, many of them lacked the motivation to truly understand the reasons why they needed to operate the system in a certain way. During the experiment, researchers also noticed that many participants had difficulties comprehending the training manual, some due to unfamiliarity with the fluid mechanic terminologies used while others due to lack of fluency reading in English. Although this aspect of participant recruitment is realistic since new hires may not necessarily be skilled within the field they are hired to work in or have a high degree of fluency in English, due to participants reading the manual within a short period of time and without external aid, this may have had a significant impact on their understanding of the materials.

Additionally, part of the data collection was done through unobtrusive observation by the researcher and through an interview with the participant after the experiment. Throughout the experiment, the researcher observed the participant while they operated the system and made noted mainly pertaining to the duration of each task and their adherence to certain procedures and sequences. The researchers had difficulties noting some of these observations due to not knowing participants' thought process but made reasonable approximations using their sequence of actions to determine when participants were starting and ending a task or beginning to wait the indicated wait time. Although this gave researchers an objective view of the types of manipulations participants made to the system, they were unable to ascertain participants' motives for these actions, whether it be on purpose to reach a certain goal by mistake while aiming to achieve another goal. On the contrary, the interview enabled researchers to understand participants' goals and purpose. However, the limitations of this interview were that participants' answers were subjective in depicting why they thought they made certain manipulations of system controls and were often hindered by hindsight (i.e., coming up with a motive in hindsight for their previous decision), meaning they may not necessarily reflect participants' actual intentions at the time the action was executed. Many participants also had trouble remembering or did not consciously know why they had made certain decisions due to the long duration and many tasks in the experiment. Furthermore, in the analysis, to account for this difference in participants' initial understanding, pre-test score was added as a covariant to the analysis of all dependent variables measuring performance, emergency response and adherence. However, ideally in an experiment, this variable should be controlled, such as by using a screening test to help recruit similar participants suitable for each category, so all participants start off with having similar levels of understanding. This would also help to ensure that exactly a third of participants are recruited from each of the 3 educational backgrounds.

In this experiment, participants did not complete an additional questionnaire immediately after reading the manual. This score would have enabled researchers to gauge their degree of improvement throughout various stages of the experiment: at the start of the experiment, immediately after reading the manual, after reading the manual and operating the system, and after an approximate 2-week period. A research study by Bose et al. examined the importance of hands-on learning by evaluating the usefulness of echocardiography simulation as compared to conventional methods on training first-year anesthesia residents with no prior experience in this field. Participants were split into 2 groups, a conventional group and a simulator group, and received 90 minutes of training followed by a written post-test. The conventional group using literatures and web resources to learn the underlying concepts of echocardiography, while the simulator group received a simulator-based teaching session. Results indicate that the simulator group performed significantly better on the post-training test and that it is a better method for teaching amateurs the basic concepts required. [57] Another research evaluated the impact of a hands-on laparoscopy course on helping participants advance their skills. Urologists participants were recruited to take a 2-day course that involves skill-based lectures, video analysis and laboratory sessions. The results of the follow-up survey obtained an average of 15.2 months later suggest that this course contributed to the expansion of participants' laparoscopy practices. [58] Since these findings have already established the necessity of having hands-on learning compliment theoretical knowledge, especially for technical tasks, researchers decided to simply have participants perform a single post-test questionnaire to examine their combined degree of improvement after completing the operation section of the experiment.

Chapter 6
Conclusion

6.1 Summary

Investigations of catastrophic incidences have found inadequate operator training program, ineffective procedures and insufficient technical expertise to be among the most common root causes. These forms of human error all relate to employee training, suggesting that the emergency could have potentially been mitigated if the company invested more resources into composing a suitable and sufficient training program that enabled operators to be adequately prepared under both normal and emergency situations. Although many researchers have studied the effects of training and different methods of presenting training materials, they have yet to examine the effects of understanding during training on an industrial process. This thesis compares the effects of a PTM (describes 'what' needs to be done) and an ETM (describes both 'what' needs to be done and 'why' it needs to be done) against 3 groups of participants differing in their educational background (CHE, ENG, and FAC) to examine the importance of understanding on the following 4 factors measuring their proficiency in process operation: 1) performance in terms of operation speed and accuracy, 2) adherence to the procedures listed in the training manual, 3) ability to respond appropriately and accurately under limited guidance during an emergency situation, and 4) amount of learned knowledge and skills retained after a 2-week period. The findings of this research study will enable the design of better and more suitable training programs for industrial companies, as well as identify the usefulness of incorporating explanatory information into training manuals.

Analysis shows that different times of repeated measure and education have a significant effect on participants' questionnaire score. All participants scored significantly higher in the post-test and retention-test compared to the pre-test, indicating that participating in this training session did have an effect on improving their overall understanding of the process. They were also seen to have similar post-test and retention-test scores, a positive sign that the training was well designed to enable participants to retain this knowledge for an approximate 2-week period. Additionally, overall, CHE outscored FAC participants likely due to their greater familiarity with the concepts and terminologies used, enable better understanding of the training materials presented.

In this experiment, both manual type and education background had no significant effect on the factors of operation time and control accuracy performance and emergency response. When only considering the effect of these 2 factors, the use of a PTM was deemed sufficient for process operation as it enabled participants to perform during normal scenarios and respond to abnormal situations at a level comparable to those using an ETM. It is important to note that this conclusion is only true when adherence is considered unimportant (see next paragraph for more details). These findings also signify the difference between knowing and applying; while certain groups of participants have greater pre-existing knowledge and familiarity with similar processes, all participants had relatively similar levels of competence in applying head knowledge to process operation. This suggests the need to add an application aspect into training programs to guide operators on how to properly apply technical knowledge into process operation.

Only manual was found to have a significant effect on APOP, where participants using an ETM had higher levels of APOP, while neither manual nor education had an effect on both ACOP and AWT. When given a simple task, most participants directly followed the procedures given. However, for complex tasks requiring the simultaneous adjustment of several controls, participants had a tendency to alter the sequence of steps to make it easier for operation. While many participants reported following procedures simply because it was written in the manual, those using an ETM had an above average degree of adherence and reported adhering because the reason in the manual convinced them. On the contrary, many using a PTM reported that they chose not to adhere because they thought their own methodology was easier and better than the manual and they did not think it was important to adhere as long as the end goal was met, resulting in a slightly below average degree of adherence. However, when instructed to wait, participants overall had a slightly above average AWT since most decided not to wait for the full duration indicated because they did not think it was necessary or they only waited until the system was in a desired state. These findings have significant implications for the design of training programs as it stresses the necessity to ensure employees fully understand the reason why certain procedures must be followed and the consequences of doing otherwise. Although this research focused more on a potential worst-case scenario, where new operators needed to self-train with the use of a written manual and without external aid, in majority of real-life scenarios, they will receive some sort of training session from the company and provided with a written training manual prior to operating on the manufacturing process. Often, there will also be an experienced operator to guide the trainee with becoming familiarized with the system and to highlight important aspects they should be aware of. Such forms of external aid serve to further enhance operators' training experience and the findings from this study accentuate the aspects that trainers should focus on and emphasize during training.

6.2 Future Work

For any future work done within this field of research, it is highly recommended that the research team collaborate with an industrial company to perform this experiment on-site and to recruit actual trainee production workers as participants. Although this will result in participants needing to learn a much larger set of skills and knowledge for the many operational tasks involved with the process, the duration of the research study can be lengthened to 1 to 2 weeks to reduce participants' mental stress by giving them sufficient time to carefully read and learn the information prior to practicing and experimenting with operating the system. Several emergency scenarios pertaining to various aspects of process operation could also be incorporated into the experiment and simulated realistically, such as using past accidents as examples, to assess participants' ability to respond effectively and efficiently to a plausible emergency that could occur. This recommendation will enable researchers to better understand the thoughts and opinions of actual workers during training and to accurately gauge the degree to which receiving training with explanatory information will improve their operation proficiency compared to training with only procedural information. As these participants are participating in this training for work purposes and these knowledge and skills are something they will need to apply on a day-to-day basis, they will likely be more motivated and put in extra effort to thoroughly understand the underlying principles of how the process operates. The environment of having this experiment performed at the production site, coupled with participants operating on either a pilot plant simulator or the actual production process system, will further add to the realism of this study and motivate participants to take this training seriously as if the scenarios were real.

Further studies should consider devising a data collection method that can capture both participants' actual performance and their thought process and underlying goals, while remaining as unobtrusive as possible so to prevent distracting or hindering participants' operation of the process and response to system changes. It is also recommended that this study be replicated while presenting the training materials in different formats, such as through video clips, simulations, virtual displays or learning from an experienced operator. As different forms of presentation can greatly impact workers' ability to learn and retain information, it is important to examine which method of presentation is most appropriate and effective for training industrial workers.

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Appendix A
Experiment Material

A.1 Recruitment Materials

A.1.1 Recruitment E-mail

Email Subject: Participants Needed for Research on the Effect of Training Methods

Email Body:

Hello,

My name is Keziah Chan and I am a Master's student in the Department of Systems Design Engineering at the University of Waterloo. Our research team also consists of Professor Shi Cao of the Department of Systems Design Engineering and Professor Ali Elkamel of the Department of Chemical Engineering.

We are currently working on a research project that examines the effect of different training methods on participants' operation and understanding of a hydraulic pump system. The recruitment flyer has been attached below in this email.

As a participant in this study, you will be asked to operate a hydraulic pump system using a training manual and to complete surveys and questionnaires. Your participation would involve 2 sessions, where session 1 lasts approximately 2 hours and session 2 lasts approximately 30 minutes. In appreciation for your time, you will receive $30 upon completion of session 1 and $10 upon completion of session 2.

I would like to assure you that the study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. If you are interested in participating, please contact me at humanfactors.uwaterloo@gmail.com.

Sincerely,

Keziah Chan

A.1.2 Recruitment Flyer

Department of Systems Design Engineering

PARTICIPANTS NEEDED FOR RESEARCH ON THE EFFECT OF TRAINING METHODS

We are looking for volunteers to take part in a study that tests the effectiveness of training methods on operation and understanding of a hydraulic pump system.

Participants will be asked to:

- *Operate a hydraulic pump system using a training manual*
- *Complete surveys and questionnaires*

Your participation would involve *2* sessions,
the first session will take 2 hour and the second will be 30 minutes.

In appreciation for your time, you will receive
$30 for Session 1** and **$10 for Session 2

For more information about this study, or to volunteer for this study, please contact:
Keziah Chan
Systems Design Engineering
Email: humanfactors.uwaterloo@gmail.com

This study has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee.

A.2 Ethics Clearance

UNIVERSITY OF WATERLOO

OFFICE OF RESEARCH ETHICS

Notification of Ethics Clearance of Application to Conduct Research with Human Participants

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Faculty Supervisor: Shi Cao **Department:** Systems Design Engineering

Faculty Supervisor: Ali Elkamel **Department:** Chemical Engineering

Student Investigator: Keziah Chan **Department:** Systems Design Engineering

ORE File #: 21951

Project Title: Effect of Training Methods on Operation and Understanding of a Hydraulic Pump System

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☑ *Human Research Ethics Committee (HREC)* ☐ *Clinical Research Ethics Committee (CREC) is pleased to inform you the above named study has been reviewed and given ethics clearance.*

Approval to start this research is effective on the ethics clearance date which is: 1/27/17 *(m/d/y)*

University of Waterloo Research Ethics Committees are composed in accordance with, and carry out their functions and operate in a manner consistent with, the institution's guidelines for research with human participants, the Tri-Council Policy Statement for the Ethical Conduct for Research Involving Humans (TCPS, 2nd edition), International Conference on Harmonization: Good Clinical Practice (ICH-GCP), the Ontario Personal Health Information Protection Act (PHIPA), the applicable laws and regulations of the province of Ontario. Both Committees are registered with the U.S. Department of Health and Human Services under the Federal Wide Assurance, FWA00021410, and IRB registration number IRB00002419 (HREC) and IRB00007409 (CREC).

The above named study is to be conducted in accordance with the submitted application (Form 101/101A) and the most recent approved versions of all supporting materials.

Ethics clearance for this study is valid until: 1/27/18 *(m/d/y). Multi-year research must be renewed at least once every 12 months unless a more frequent review has otherwise been specified by the Research Ethics Committee (Form 105). Studies will only be renewed if the renewal report is received and approved before the expiry date. Failure to submit renewal reports by the expiry date will result in the investigators being notified ethics clearance has been suspended and Research Finance being notified the ethics clearance is no longer valid.*

Level of review:

☑ *Delegated review*

☐ *Full committee review meeting date:* ________________ *(m/d/y)*

Signed on behalf of: ☑ *HREC Chair* ☐ *CREC Chair*

____

☐ *Jannet Ann Leggett, JD, Chief Ethics Officer, jannet.a.leggett@uwaterloo.ca, ext. 36005*

☑ *Julie Joza, MPH, Senior Manager, jajoza@uwaterloo.ca, ext. 38535*

☐ *Sacha Geer, PhD, Manager, sgeer@uwaterloo.ca, ext. 37163*

☐ *Nick Caric, MDiv, Research Ethics Advisor, ncaric@uwaterloo.ca, ext. 30321*

This is an official document. Retain for your files.
You are responsible for obtaining any additional institutional approvals that might be required to complete this study.

A.3 Experiment Materials

A.3.1 Information Letter

INFORMATION LETTER

Project Title:	**Effect of Training Methods on Operation and Understanding of a Hydraulic Pump System**
Student Investigator:	**Keziah Chan, Department of Systems Design Engineering, humanfactors.uwaterloo@gmail.com**
Faculty Advisors:	**Shi Cao, Department of Systems Design Engineering, shi.cao@uwaterloo.ca, 519-888-4567 x36377**
	Ali Elkamel, Department of Chemical Engineering, aelkamel@uwaterloo.ca, 519-888-4567 x37157

Overview

This research study is being conducted as part of Keziah Chan's Master's thesis work. Many researchers have studied the importance of employee training and training manuals on employee performance during normal process operation. However, to date, no research studies have examined the types of information that should be included in training manuals and their effectiveness on improving operator performance and usage of the manual during both normal operations and emergency situations. Thus, this study aims to supplement the lack of research in this area by examining the effects of different training methods on improving human performance, knowledge retention, and emergency response during operation of a hypothetical simulation of an industrial pilot plant. It investigates the practicality of different training instruction manuals and their impact on participants' understanding of a hydraulic pump system and performance in terms of accuracy and speed during both normal operation and emergency situations. Through the collection of data on participants' manipulation of system controls to achieve operation goals and criteria, as well as their responses to surveys and questionnaire, the researchers hope to determine whether understanding the reasoning behind certain operations will improve participants' performance, decision making skills and knowledge of the system. The results of this study are expected to aid the development of better employee training sessions through compiling more functional, safe and effective training manuals geared towards educating workers to improve their performance, which significantly influences decision making, product quality, production costs and time.

Study Details

Your participation in this study is completely voluntary and you may decline to answer any questions you may wish. If you would like to stop the study or withdraw your participation at any time, you may do so by advising the researcher without any penalty.

1

Participation in this study involves 2 separate sessions, with the second session occurring 14 days after the first session. If you agree to participate, when you sign up for your first session, which is approximately 120 minutes long, you will also be asked to simultaneously sign up for the second session, which is approximately 30 minutes long.

Session 1: To be completed today

In session 1, you will be informed about the purpose of this study and the procedure you will be asked to perform. You will also be given an opportunity to ask the researcher any questions you may have concerning the study. Please note that at any time throughout the entire study, you may continue to raise any questions or concerns that arise to the researcher. If you are still interested in participating, you will be given a consent form to read over and sign.

Prior to the start of the actual experiment, you will first be asked to fill out a demographic survey and a questionnaire that assesses your current level of knowledge and skill regarding hydraulic pump system operation and concepts. You will then be given a training manual written in the form of a hypothetical industrial case study to read over, after which you will immediately begin the experiment. The first set of operation tasks will be considered a practice trial.

In this experiment, you will be asked to operate the pump system in accordance to the procedures outlined in the training manual. As will be further explained in the manual, this experiment will be performed assuming you are a new operator placed in charge of the wash system (i.e., the hydraulic pump system) at a metal manufacturing plant. As part of your employee training session, you will be operating a pilot plant wash system based on a hypothetical case study that compiles several common scenarios encountered during production. Specifically, your task is to manipulate system controls (i.e., various valves) to operate the various streams of the wash system and adjust their flow rates per order requirements, while simultaneously upholding operating criteria set by the company. While performing this experiment, you have 3 objectives (i.e., operating criteria) that you should aim to always achieve: (1) maintain inlet flow rate within the range of 15-20 L/min, (2) maintain a pressure drop less than 2 psi and (3) complete all changes made to the system as quickly as possible. You will be performing a system start-up procedure, followed by 3 normal operation trials of this experiments, an emergency response task, and finally a system shutdown procedure.

At the end of this experiment, you will be asked to complete a questionnaire that assesses how much you have learned about operating a hydraulic pump system and its related principles, as well as a practicality survey that inquires about your usage of the manual and how helpful you found it to be in aiding your operation of the pump system.

Session 1 of the study should take no more than 2 hours in duration. At the end of this session, you will be given $30.00 as remuneration for participating in session 1 and asked to sign a remuneration self-declaration form as proof of receiving remuneration. You will also be given a feedback form of the study and reminded to come back for session 2 of the study 14 days later. Two days prior to your scheduled appointment for session 2, the researcher will send you an email reminder confirming your appointment.

Session 2: To be completed 14 days later

When you return, you will be given instructions for similar tasks in session 2.

Session 2 of the study should take no more than 30 minutes in duration. At the end of this session, you will be given an additional $10.00 as remuneration for participating in session 2 of the study and asked to sign another remuneration self-declaration form as proof of receiving the remuneration.

Risks and Benefits

There are no anticipated risks associated with the study to you as a participant. The hydraulic pump system you will be interacting with pumps water and operates at low pressures.

There are no direct benefits to you for participating in this study. However, this experiment gives you a chance to interact with basic industrial equipment and learn some basic principles on the operation of hydraulic pump systems. The results of this study are expected to improve employee training sessions through the development of suitable training instruction manuals.

Eligibility Requirements for Participation

All participants must be at least 18 years old and currently enrolled as either an undergraduate or graduate student in the University of Waterloo.

Confidentiality and Data Retention

All information that you provide is considered completely confidential; your name will not be associated in any way with the data collected in this study. Furthermore, because the interest of this study is in the average responses of the entire group of participants, you will not be identified individually in any way in any written reports of this research. All identifying information will be removed from the data records prior to storage. Paper records of data will be retained in a locked filing cabinet while electronic data files will be stored on a secure laptop within a locked cabinet in EC4 2127, to which only researchers associated with this study will have access, and confidentially shredded after being retained for 5 years.

Remuneration

In appreciation for your time, you will receive $30.00 as remuneration for participating in session 1 and an additional $10.00 for participating in session 2, for a total possible remuneration amount of $40.00 in this study. The amount you will receive in this study is taxable and it is your responsibility to report this amount for income tax purposes.

For session 1, if you choose to withdraw your participation before the completion of this session, you will receive remuneration at a prorated rate of $2.50 per every 15 minutes spend in the study. However, for session 2, if you choose to withdraw your participation before the completion of this session, we will not be able to reimburse you for your time.

Ethic Review and Clearance

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE 21951). However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, please contact the Chief Ethics Officer, Office of Research Ethics, at 1-519-888-4567, ext. 36005 or ore-ceo@uwaterloo.ca.

A.3.2 Consent Form

UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING
Department of Systems
Design Engineering

CONSENT OF PARTICIPANT

By signing this consent form, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

Project Title:	**Effect of Training Methods on Operation and Understanding of a Hydraulic Pump System**
Student Investigator:	**Keziah Chan, Department of Systems Design Engineering, humanfactors.uwaterloo@gmail.com**
Faculty Advisors:	**Shi Cao, Department of Systems Design Engineering, shi.cao@uwaterloo.ca, 519-888-4567 ext. 36377**
	Ali Elkamel, Department of Chemical Engineering, aelkamel@uwaterloo.ca, 519-888-4567 ext. 37157

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study being conducted by Keziah Chan, a Master's student in the University of Waterloo's Department of Systems Design Engineering, who is working under the supervision of Professor Shi Cao of the Department of Systems Design Engineering and Professor Ali Elkamel of the Department of Chemical Engineering. I have made this decision based on the information I have received in the information letter and after being verbally informed by one of this study's researchers about the contents, requirements, risks and benefits of this experiment. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted.

As a participant in this study, I realize that there are 2 sessions to this study. I understand that I will be operating a hydraulic pump system and completing several surveys and questionnaires. I am aware that I may withdraw from the study without penalty at any time by advising the researchers of this decision.

This project has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE 21951). I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Chief Ethics Officer, Office of Research Ethics, at 1-519-888-4567, ext. 36005 or ore-ceo@uwaterloo.ca.

519-888-4567 | uwaterloo.ca | 200 UNIVERSITY AVENUE WEST, WATERLOO, ON, CANADA N2L 3G1

UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING
Department of Systems
Design Engineering

	Please Circle One	Please Initial Your Choice
I agree to participate in session 1 of this study. [About 120 minutes]	YES NO	________
I also agree to participate in session 2 of this study. [About 30 minutes]	YES NO	________

____
Participant Name

____
Signature of Participant

____
Dated at Waterloo, Ontario

____
Witness Name

____
Signature of Witness

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A.3.3 Procedural Training Manual

<- ELECTRO-PLATE INC. ->

TRAINING MANUAL

SMALL-SCALED PRODUCTION LINE ~ WASH SYSTEM

CONGRATULATIONS ON YOUR EMPLOYMENT AT ELECTRO-PLATE INC.

POSITION: *WASH SYSTEM OPERATOR*
PRODUCTION LINE: *SMALL-SCALED*
LOCATION: *WATERLOO, ONTARIO, CANADA*

P

SCENARIO

You are a newly hired operator reporting for your first day of work at Electro-Plate Inc., which is a manufacturing company that produces a variety of metal plates that are electroplated to obtain distinct surface properties. You have been assigned to Electro-Plate's main manufacturing plant in Waterloo, where you are responsible for the operation of the wash system in their small-scaled production line, which is used for washing small-sized metal plates and ensuring their cleanliness prior to electroplating. While the production manager *(enacted by the researcher)* is busy overseeing the operation of all production lines in the plant, she doesn't have time to personally train you and has simply left you to self-learn using a pilot plant of the wash system and a training manual. However, she is available for clarifications and to answer any questions you might have.

INTRODUCTION

About Electro-Plate Inc.

Electro-Plate Inc. is a metal manufacturing and electroplating company headquartered in Waterloo, Ontario, Canada. They produce metals, in the form of metal plates, that are specially electroplated to enhance or inhibit certain surface properties. These metal plates are then sold to specialized companies (*customers*) to be crafted into functional objects or parts for everyday consumer use.

Electroplating Process

Electro-Plate's main manufacturing plant consists of several production lines, each signifying an electroplating industrial process and designed to produce metal plates of a specified range of sizes. **Electroplating is a surface finishing process generally used to change the surface properties of an object**, such as corrosion resistance (chemical change), aesthetic appearance (physical change) and surface hardness (mechanical change). This process utilizes electric currents to form a coherent metal coating on the surface of an electrode.

Prior to the actual process of electroplating, the metal plates undergo a cleaning cycle where they are thoroughly cleansed in preparation for surface finishing. Plate cleanliness is an important standard upheld in the majority of manufacturing industries throughout their entire production process for reasons such as hygiene, purification and preventing contamination. Specifically, the **cleaning of parts is an essential start to electroplating as it removes impurities** (i.e., oil molecules and contaminants) from the surface of the object and **determines the degree of adhesion of the coating**. As a new hire, you are responsible for operating the wash system section of the cleaning cycle, where metal plates are cleansed under a spray bath of Chemical A solution.

Wash System

The **wash system (see Figure 1) is a closed system** that operates using a centrifugal pump that continuously pumps water from the water tank to an elevated height, where it is then diverted from the main pipeline into a maximum of 4 streams (stream A, stream B, diluting and cooling streams) and cycled back into the water tank. Of these 4 streams, **stream B and the diluting and cooling streams require a specified flow rate of water** depending on the type and quantity of plates being washed. As high precision is needed, each of these 3 streams are equipped with a manual flow control valve which operators can use to regulate their flow. The remaining water is sent through **stream A, which has no special flow requirements** as it is designed to always have a minimum flow rate of water to enable formation of Chemical A solution during process operation.

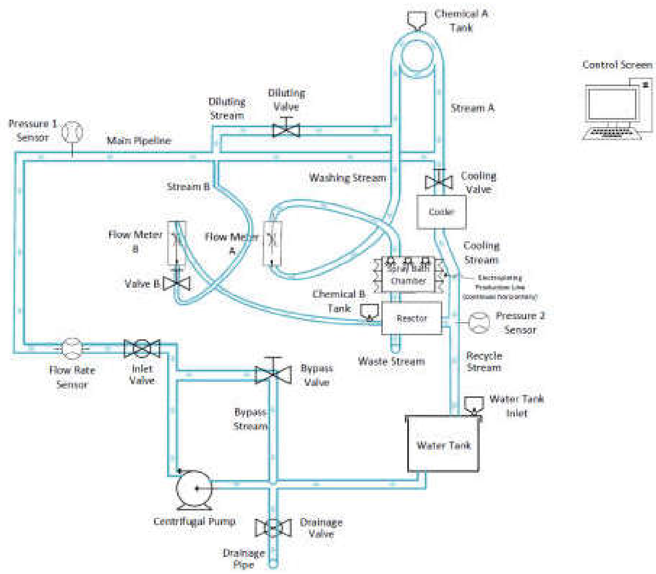

Figure 1 – Diagram of the Wash System Pilot Plant

- STAGE 1: From the main pipeline, water is diverted upwards through stream A where it is combined with a specified mass flow rate of powdered Chemical A. This solution is circulated 540° in the stream to ensure **Chemical A is fully dissolved to form Chemical A solution**.

- STAGE 2: Chemical A solution is further diluted with water as stream A is combined with the diluting stream to form the washing stream. **Flow meter A indicates the flow rate of the washing stream** prior to being used in the spray bath chamber. Depending on the type of metal and size of plate being washed, the required concentration of Chemical A in the washing stream differs. Thus, at the start of each manufacturing order, operators need to use the control screen to input the mass flow rate at which Chemical A is added to stream A. Additionally, the purpose of the **diluting valve is to control the flow rate of water through the diluting stream to dilute the Chemical A solution to the defined range of concentrations of the washing stream**.

- STAGE 3: The only location where the wash system is employed on the small-scaled production line (on which metal plates are transported) is the spray bath chamber. As metal plates enter the chamber, they are clamped at the edges and slowly rotated under a high-pressure spray bath of the washing stream for 1 minute before being removed and transported to the next system on the production line. On the other hand, **spent water** from the chamber (**combination of the removed impurities and washing stream**) is discharged into the reactor.

- STAGE 4: From the main pipeline, water diverted as stream B, flowing at a specified flow rate, is used to transport a specified mass flow rate of Chemical B in its solid state into the reactor. **Flow meter B indicates the flow rate of stream B, while valve B is used to control the flow through stream B to ensure it operates at the specified rate**. Additionally, at the start of manufacturing each order, operators need to use the control screen to input the necessary mass flow rate at which Chemical B is added to stream B.

- STAGE 5: As both the spent water from the spray bath chamber and stream B enter the reactor, a series of reactions occur where the **impurities and Chemical A from the spent water aggregate onto the solid particles of Chemical B in stream B, forming a precipitate** (i.e., solid substance). This precipitate is then filtered and removed from the reactor through a waste stream, while the remaining purified water is discharged into the recycle stream.

  NOTE: ***Reactions in the reactor are exothermic (i.e., heat is released from the reaction)***.

- STAGE 6: From the main pipeline, water diverted as the cooling stream is sent through a cooler, where water is cooled to a temperature of 5 °C. Electro-Plate requires that the **cooling stream maintains a minimum flow rate equivalent to the cooling valve being opened by 1 rotation (i.e., 360 degrees) during process operation.**

- STAGE 7: The cooling stream is combined with the purified water at the reactor discharge to form the recycle stream and is then recycled back into the water storage tank pipe. The **cooling stream acts as a preventative means to lower the temperature of the recycle stream, especially when it rises above the critical temperature in emergency situations**.

  NOTE: A temperature sensor is installed at the reactor exit and attached to a high-level alarm, which lights up on the control screen when temperature exceeds the critical temperature of 80 °C. When reactor temperature exceeds 80 °C, an emergency condition arises where the reactor is in danger of overheating (i.e., reaching a temperature of 100 °C) and must be cooled immediately to prevent potential accidents from occurring.

Chemical A and Chemical B

Chemical A is a cleaning formulation that can thoroughly **remove approximately 99% of all impurities from the surface of metals and alloys**. It is a **highly soluble powder that is utilized by dissolving it in water and diluting the solution to the necessary range of concentrations**.

Chemical B is a water purification formulation that **removes impurities from contaminated water by aggregating them on its surface**. It is a **non-soluble solid in the form of small pellets that require fluid flow at a specified rate to transport them to the reactor**.

Overheating

Overheating is an extremely hazardous condition that commonly occurs in production processes with exothermic reactions. The large amounts of heat released can accumulate to high temperatures, causing serious and potentially catastrophic damages to the reactor and its surrounding system, such as leakages from pipe ruptures and ignition of flammable chemicals.

Overheating occasionally occurs in the wash system reactor due to runaway reactions or spontaneous reactions caused by reactive impurities. Exothermic reactions occur as Chemical B is used to purge the spent water of Chemical A and impurities to obtain pure water. The **precipitate from this reaction is highly flammable** at temperatures above 100 °C and special care must be taken to ensure its surrounding environment is kept cool and away from sparks and flames. Additionally, the **pipeline becomes susceptible to ruptures** at temperatures above 100 °C. As such, **Electro-Plate has set the critical temperature of the reactor to 80 °C** and installed a **high-level alarm that lights up on the control screen if the exit reactor temperature exceeds 80 °C**.

When the alarm lights up, operators should immediately **maximize flow rate through the cooling stream** to cool down the water discharged from the reactor exit**,** while still **upholding all operating criteria**. The **concentrations of Chemicals A and B should be maintained at or within the specified rates or ranges** to continue operation of the spray bath so the process remains undisrupted. However, if **overheating persists for over 2 minutes,** the production line should be stopped and the **flow rates of Chemicals A and B should be set to zero** to prevent any further reactions from occurring and to **focus more water for cooling**. *NOTE: Water in the washing stream and stream B are at room temperature and are not cooled prior to entering the reactor. Although they have a higher temperature than the cooling stream, it is still significantly lower than the overheating reactor.*

Operating Criteria

Electro-Plate has strict product quality control standards that must be met prior to product shipment to customer. Specifically pertaining to the wash system, Electro-Plate specified 3 operating criteria that must be met by the operator whenever it is in operation, including overheating emergencies.

1) **Maintain an inlet flow rate within the range of 19 to 22 L/min.**
2) **Maintain pressure drop ($\Delta P = P2 - P1$) less than 4 psi across the wash system.**
3) **Complete all operation instructions from the manager as quickly as possible.**

These 3 criteria will be used to measure your performance. Fulfillment of these 3 criteria are important to ensure product quality and operation efficiency standards established by Electro-Plate and their customers.

SAFETY CRITERIA: The temperature at the reactor exit must be kept below the critical temperature of 80 °C at all times. During overheating, achieving this safety criteria is top priority for operators, while upholding operating criteria becomes secondary.

Production Notifications and Operation Alerts

<Production Notifications> and <Operation Alerts> are popup messages that appear on operators' control screens.

<Production Notifications> are used to notify operators of the next sales order on the schedule, completion of an order and changes to production. Notifications of **sales orders are indicated by a blue header**. Each notification indicates the flow range of water required for stream A (indicated by flow meter A) and flow rate required for stream B (indicated by flow meter B), as well as the **mass flow rates required for Chemical A and Chemical B (to be inputted by the operator on the control screen)**. *NOTE: These flow rates are proposed by the production manager to satisfy customer demands. Operators are expected to operate at these rates unless manufacturing issues or emergencies arise, in which case they should be adjusted accordingly.*

<Operation Alerts> are displayed with a **red header and used to notify operators when an emergency arises.** In this training, only emergency alerts concerning overheating will be shown.

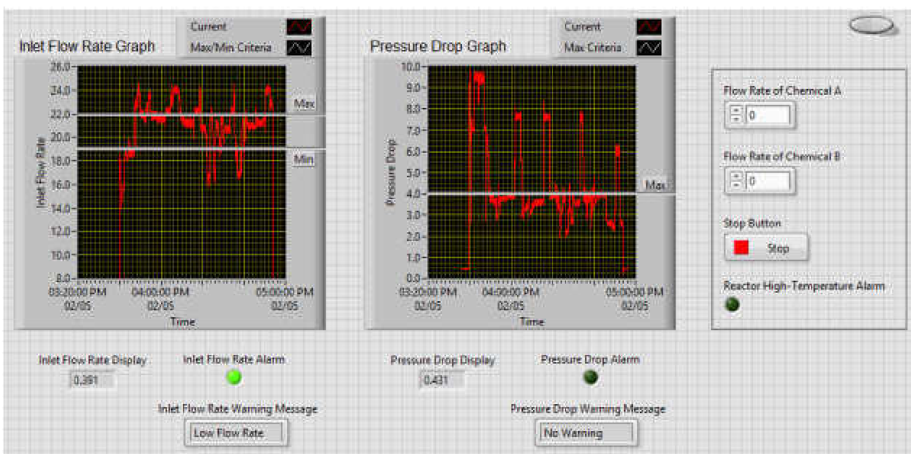

Figure 2 –Control Screen for the Wash System

Figure 2 shows an illustration of the control screen for the wash system. In the control screen, there are input boxes where the mass flow rates of Chemicals A and B can be inputted, as well as an "Overheating Alarm" which will light up when the critical temperature is exceeded. Pressure drop can be determined from the "Pressure Drop Graph" and "Pressure Drop Display" on the control screen, while inlet flow rate can be determined from the "Inlet Flow Rate Graph" and "Inlet Flow Rate Display". If **inlet flow rate and/or pressure drop fails to meet the operating criteria, their corresponding alarm will light up on the control screen** and operators should immediately and quickly adjust parameters so they are within the required operating criteria range.

PART A: START-UP OF WASH SYSTEM

Step 1) Ensure the power switch of the pump is turned off. Push the switch downwards to turn off the power.

Step 2) Ensure all 6 valves are fully closed (i.e., inlet, bypass, cleansing, purging, cooling and drainage valves). Ball valves can be closed by turning it 90 degrees to the left. Alternatively, flow control valves can be closed by turning it in a clockwise direction all the way.

Step 3) Ensure the water tank is filled and the stopper is placed over the tank inlet.

Step 4) Plug in the pump and sensors' electrical plugs into an electrical outlet. If using an extension cord, ensure the power bar is switched on.

Step 5) Turn on the power switch of the pump by pushing the switch upwards.

Step 6) After 30 seconds, gradually open the inlet valve by turning it 90 degrees to the right.

Step 7) Slightly open the diluting and bypass valves by turning them counterclockwise to get rid of the air bubbles in the main pipeline.

Step 8) Check the entire wash system to ensure there are no leakages.

Step 9) Wait for the system to reach steady state, as indicated by a constant inlet flow rate, and maintain this condition for at least 1 minute.

PART B: OPERATION OF WASH SYSTEM

For each new production order that is manufactured, use the information listed in its production notification (refer to notification system on the control screen) to operate the wash system in accordance with the following **general procedure during normal operation**:

Step 1) Turn the cooling valve counterclockwise by 1 rotation to turn on the cooling stream.

At the same time, simultaneously turn the bypass and cooling valves as needed to maintain inlet flow rate and pressure drop within specified operating criteria range.

Step 2) If ***current stream B flow rate < required stream B flow rate***, slowly turn valve B counterclockwise to increase flow rate of flow meter B.
If ***current stream B flow rate > required stream B flow rate***, slowly turn valve B clockwise to decrease flow rate of flow meter B.

At the same time, simultaneously turn the bypass and cooling valves as needed to maintain inlet flow rate and pressure drop within specified operating criteria range.

Step 3) Input the required mass flow rate of Chemical B onto the control screen.

Step 4) If ***current washing stream flow rate < required washing stream flow range***, slowly turn the diluting valve counterclockwise to increase flow rate of flow meter A.
If ***current washing stream flow rate > required washing stream flow range***, slowly turn the diluting valve clockwise to decrease flow rate of flow meter A.

At the same time, simultaneously adjust valve B as needed to maintain flow rate of stream B at the required rate, while also turning the bypass and cooling valves as needed to maintain inlet flow rate and pressure drop within specified operating criteria range.

Step 5) Input the required mass flow rate of Chemical A onto the control screen.

Step 6) Ask the manager (the researcher) to come verify all operating parameters are met.

Step 7) Maintain this condition for 2 minutes.

Step 8) Notify the manager that you have completed the production order.

After the completion of each production order, the entire production line will undergo a **product changeover**. During changeover, operate the wash system in accordance with the following **flush cycle procedure**:

Step 9) Set flow rate of Chemical A to 0 and Chemical B to 5 g/min on the control screen.

Step 10) Flush the system for product changeover for 1 minute while considering that operating criteria **does NOT need to be met**.

Fully close the cooling and bypass valves by turning them in a clockwise direction all the way. Then, open both valve B and the diluting valve by an additional 3 rotations by turning them in a counterclockwise direction.

Step 11) Notify the manager that you have completed the product changeover.

SAMPLE NOTIFICATION ALERTS

< Start Production Order 001 >

<--- PRODUCTION NOTIFICATION --->

Order Number: 001

Metal/Alloy: Copper
Dimensions: 20" (l) x 20" (w) x 1" (h)

	Flow Rate
Chemical A	25 g/min
Chemical B	100 g/min
Washing Stream	9-11 L/min
Stream B	3 L/min

< Completion of Production Order 001 >

<--- PRODUCTION NOTIFICATION --->

Order Number: 001

SHIPPED

Metal/Alloy: Copper
Dimensions: 20" (l) x 20" (w) x 1" (h)

< Product Changeover – Flush Cycle >

PART C: SHUTDOWN OF WASH SYSTEM

Step 1) Operate an additional flush cycle of the system for 1 minute.

Step 2) Fully close the inlet ball valve by turning it 90 degrees to the left.

Step 3) Ensure the drainage valve remains closed.

Step 4) Turn off the power switch of the pump by pushing the switch downwards.

Step 5) Unplug the pump and sensors' electrical plugs from the electrical outlet. If an extension cord was used, switch off the power bar.

Step 6) Fully open valve B and the inlet, bypass, diluting and cooling valves to cycle all residual water in the system back into the water tank by turning ball valves 90 degrees to the right and flow control valves in a counterclockwise direction all the way.

Step 7) Wait for the water in the main pipeline to fully drain out, then fully close all 5 valves by turning ball valves 90 degrees to the left and flow control valves in a clockwise direction all the way.

A.3.4 Explanatory Training Manual

<- ELECTRO-PLATE INC. ->

TRAINING MANUAL

SMALL-SCALED PRODUCTION LINE ~ WASH SYSTEM

CONGRATULATIONS ON YOUR EMPLOYMENT AT ELECTRO-PLATE INC.

POSITION: *WASH SYSTEM OPERATOR*
PRODUCTION LINE: *SMALL-SCALED*
LOCATION: *WATERLOO, ONTARIO, CANADA*

SCENARIO

You are a newly hired operator reporting for your first day of work at Electro-Plate Inc., which is a manufacturing company that produces a variety of metal plates that are electroplated to obtain distinct surface properties. You have been assigned to Electro-Plate's main manufacturing plant in Waterloo, where you are responsible for the operation of the wash system in their small-scaled production line, which is used for washing small-sized metal plates and ensuring their cleanliness prior to electroplating. While the production manager *(enacted by the researcher)* is busy overseeing the operation of all production lines in the plant, she doesn't have time to personally train you and has simply left you to self-learn using a pilot plant of the wash system and a training manual. However, she is available for clarifications and to answer any questions you might have.

INTRODUCTION

About Electro-Plate Inc.

Electro-Plate Inc. is a metal manufacturing and electroplating company headquartered in Waterloo, Ontario, Canada. They produce metals, in the form of metal plates, that are specially electroplated to enhance or inhibit certain surface properties. These metal plates are then sold to specialized companies (*customers*) to be crafted into functional objects or parts for everyday consumer use.

Electroplating Process

Electro-Plate's main manufacturing plant consists of several production lines, each signifying an electroplating industrial process and designed to produce metal plates of a specified range of sizes. **Electroplating is a surface finishing process generally used to change the surface properties of an object**, such as corrosion resistance (chemical change), aesthetic appearance (physical change) and surface hardness (mechanical change). This process utilizes electric currents to form a coherent metal coating on the surface of an electrode.

Prior to the actual process of electroplating, the metal plates undergo a cleaning cycle where they are thoroughly cleansed in preparation for surface finishing. Plate cleanliness is an important standard upheld in the majority of manufacturing industries throughout their entire production process for reasons such as hygiene, purification and preventing contamination. Specifically, the **cleaning of parts is an essential start to electroplating as it removes impurities** (i.e., oil molecules and contaminants) from the surface of the object and **determines the degree of adhesion of the coating**. As a new hire, you are responsible for operating the wash system section of the cleaning cycle, where metal plates are cleansed under a spray bath of Chemical A solution.

Wash System

The **wash system (see Figure 1) is a closed system** that operates using a centrifugal pump that continuously pumps water from the water tank to an elevated height, where it is then diverted from the main pipeline into a maximum of 4 streams (stream A, stream B, diluting and cooling streams) and cycled back into the water tank. Of these 4 streams, **stream B and the diluting and cooling streams require a specified flow rate of water** depending on the type and quantity of plates being washed. As high precision is needed, each of these 3 streams are equipped with a manual flow control valve which operators can use to regulate their flow. The remaining water is sent through **stream A, which has no special flow requirements** as it is designed to always have a minimum flow rate of water to enable formation of Chemical A solution during process operation.

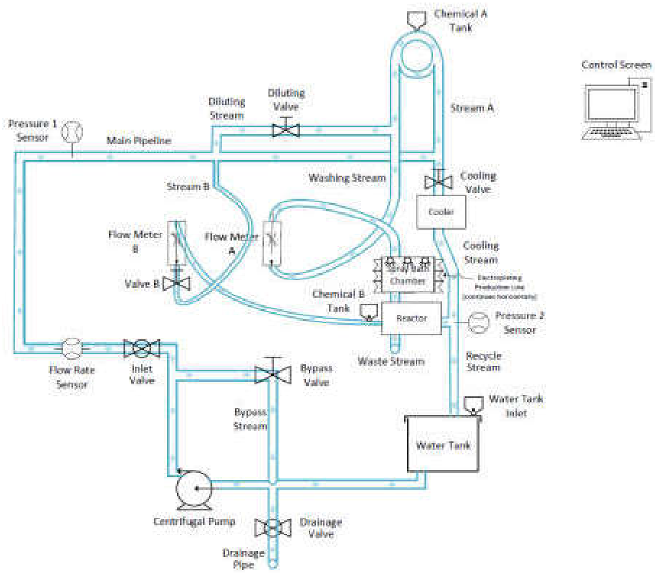

Figure 1 – Diagram of the Wash System Pilot Plant

- STAGE 1: From the main pipeline, water is diverted upwards through stream A where it is combined with a specified mass flow rate of powdered Chemical A. This solution is circulated 540° in the stream to ensure **Chemical A is fully dissolved to form Chemical A solution**.

- STAGE 2: Chemical A solution is further diluted with water as stream A is combined with the diluting stream to form the washing stream. **Flow meter A indicates the flow rate of the washing stream** prior to being used in the spray bath chamber. Depending on the type of metal and size of plate being washed, the required concentration of Chemical A in the washing stream differs. Thus, at the start of each manufacturing order, operators need to use the control screen to input the mass flow rate at which Chemical A is added to stream A. Additionally, the purpose of the **diluting valve is to control the flow rate of water through the diluting stream to dilute the Chemical A solution to the defined range of concentrations of the washing stream**.

- STAGE 3: The only location where the wash system is employed on the small-scaled production line (on which metal plates are transported) is the spray bath chamber. As metal plates enter the chamber, they are clamped at the edges and slowly rotated under a high-pressure spray bath of the washing stream for 1 minute before being removed and transported to the next system on the production line. On the other hand, **spent water** from the chamber (**combination of the removed impurities and washing stream**) is discharged into the reactor.

- STAGE 4: From the main pipeline, water diverted as stream B, flowing at a specified flow rate, is used to transport a specified mass flow rate of Chemical B in its solid state into the reactor. **Flow meter B indicates the flow rate of stream B, while valve B is used to control the flow through stream B to ensure it operates at the specified rate**. Additionally, at the start of manufacturing each order, operators need to use the control screen to input the necessary mass flow rate at which Chemical B is added to stream B.

- STAGE 5: As both the spent water from the spray bath chamber and stream B enter the reactor, a series of reactions occur where the **impurities and Chemical A from the spent water aggregate onto the solid particles of Chemical B in stream B, forming a precipitate** (i.e., solid substance). This precipitate is then filtered and removed from the reactor through a waste stream, while the remaining purified water is discharged into the recycle stream.

  NOTE: ***Reactions in the reactor are exothermic (i.e., heat is released from the reaction)***.

- STAGE 6: From the main pipeline, water diverted as the cooling stream is sent through a cooler, where water is cooled to a temperature of 5 °C. Electro-Plate requires that the **cooling stream maintains a minimum flow rate equivalent to the cooling valve being opened by 1 rotation (i.e., 360 degrees) during process operation.**

- STAGE 7: The cooling stream is combined with the purified water at the reactor discharge to form the recycle stream and is then recycled back into the water storage tank pipe. The **cooling stream acts as a preventative means to lower the temperature of the recycle stream, especially when it rises above the critical temperature in emergency situations**.

  NOTE: A temperature sensor is installed at the reactor exit and attached to a high-level alarm, which lights up on the control screen when temperature exceeds the critical temperature of 80 °C. When reactor temperature exceeds 80 °C, an emergency condition arises where the reactor is in danger of overheating (i.e., reaching a temperature of 100 °C) and must be cooled immediately to prevent potential accidents from occurring.

Chemical A and Chemical B

Chemical A is a cleaning formulation that can thoroughly **remove approximately 99% of all impurities from the surface of metals and alloys**. It is a **highly soluble powder that is utilized by dissolving it in water and diluting the solution to the necessary range of concentrations**.

Chemical B is a water purification formulation that **removes impurities from contaminated water by aggregating them on its surface**. It is a **non-soluble solid in the form of small pellets that require fluid flow at a specified rate to transport them to the reactor**.

Overheating

Overheating is an extremely hazardous condition that commonly occurs in production processes with exothermic reactions. The large amounts of heat released can accumulate to high temperatures, causing serious and potentially catastrophic damages to the reactor and its surrounding system, such as leakages from pipe ruptures and ignition of flammable chemicals.

Overheating occasionally occurs in the wash system reactor due to runaway reactions or spontaneous reactions caused by reactive impurities. Exothermic reactions occur as Chemical B is used to purge the spent water of Chemical A and impurities to obtain pure water. The **precipitate from this reaction is highly flammable** at temperatures above 100 °C and special care must be taken to ensure its surrounding environment is kept cool and away from sparks and flames. Additionally, the **pipeline becomes susceptible to ruptures** at temperatures above 100 °C. As such, **Electro-Plate has set the critical temperature of the reactor to 80 °C** and installed a **high-level alarm that lights up on the control screen if the exit reactor temperature exceeds 80 °C**.

When the alarm lights up, operators should immediately **maximize flow rate through the cooling stream** to cool down the water discharged from the reactor exit**,** while still **upholding all operating criteria**. The **concentrations of Chemicals A and B should be maintained at or within the specified rates or ranges** to continue operation of the spray bath so the process remains undisrupted. However, if **overheating persists for over 2 minutes,** the production line should be stopped and the **flow rates of Chemicals A and B should be set to zero** to prevent any further reactions from occurring and to **focus more water for cooling**. *NOTE: Water in the washing stream and stream B are at room temperature and are not cooled prior to entering the reactor. Although they have a higher temperature than the cooling stream, it is still significantly lower than the overheating reactor.*

Operating Criteria

Electro-Plate has strict product quality control standards that must be met prior to product shipment to customer. Specifically pertaining to the wash system, Electro-Plate specified 3 operating criteria that must be met by the operator whenever it is in operation, including overheating emergencies.

1) **Maintain an inlet flow rate within the range of 19 to 22 L/min.**
2) **Maintain pressure drop ($\Delta P = P2 - P1$) less than 4 psi across the wash system.**
3) **Complete all operation instructions from the manager as quickly as possible.**

These 3 criteria will be used to measure your performance. Fulfillment of these 3 criteria are important to ensure product quality and operation efficiency standards established by Electro-Plate and their customers.

SAFETY CRITERIA: The temperature at the reactor exit must be kept below the critical temperature of 80 °C at all times. During overheating, achieving this safety criteria is top priority for operators, while upholding operating criteria becomes secondary.

Production Notifications and Operation Alerts

<Production Notifications> and <Operation Alerts> are popup messages that appear on operators' control screens.

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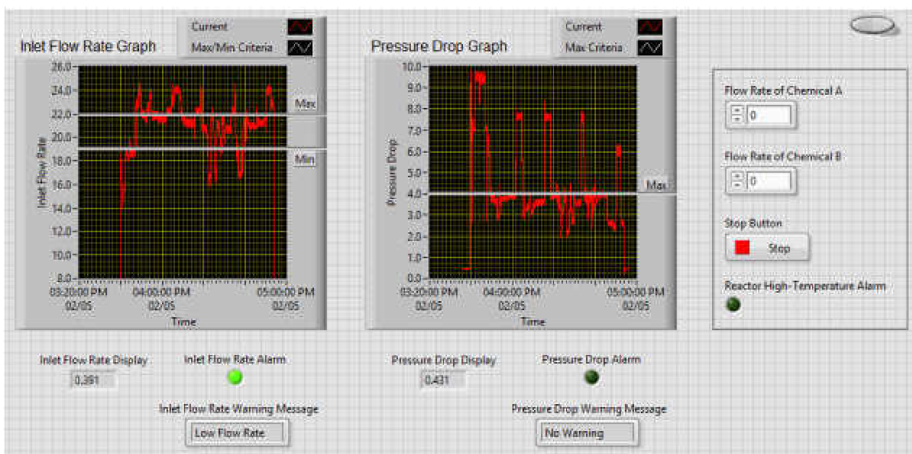

Figure 2 –Control Screen for the Wash System

Figure 2 shows an illustration of the control screen for the wash system. In the control screen, there are input boxes where the mass flow rates of Chemicals A and B can be inputted, as well as an "Overheating Alarm" which will light up when the critical temperature is exceeded. Pressure drop can be determined from the "Pressure Drop Graph" and "Pressure Drop Display" on the control screen, while inlet flow rate can be determined from the "Inlet Flow Rate Graph" and "Inlet Flow Rate Display". If **inlet flow rate and/or pressure drop fails to meet the operating criteria, their corresponding alarm will light up on the control screen** and operators should immediately and quickly adjust parameters so they are within the required operating criteria range.

PART A: START-UP OF WASH SYSTEM

Operation of Valves

Valves use mechanisms installed into the pipeline to control the amount of flow through the pipe. Specifically, this wash system uses 2 types of valves: ball valves (Figure 3) and flow control valves (Figure 4).

Ball valves operate by rotating a ball with a hole through it to either restrict or enable flow through the pipe. As shown in Figure 3, these valves are opened by turning the handle 90 degrees to the right so that it is parallel to the pipeline, indicating that the hole in the ball is in-line with the flow, and closed by turning the handle 90 degrees to the left so that it is perpendicular to the pipeline, indicating that the flow is being restricted by the closed side of the ball. [6]

Flow control valves operate by raising and lowering a gate to restrict, enable and control the quantity of flow through the pipeline. Using a flow control valve, as opposed to other valves such as ball valves, provides operators with **greater precision in controlling and maintaining the flow rate** within a certain range. As shown in Figure 4, a clockwise rotation of this valve will close the gate to a greater degree and reduce flow rate through the stream, while a counterclockwise rotation will open the gate to a greater degree and increase flow rate through the stream. [7]

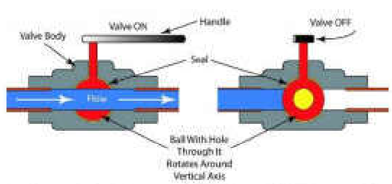

Figure 3 – Operation of Ball Valves [6]

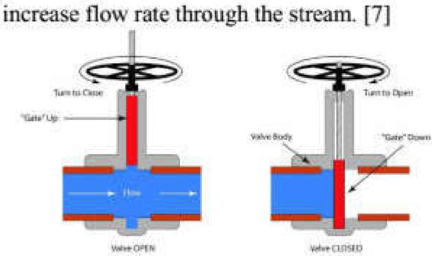

Figure 4 – Operation of Flow Control Valves [7]

Standard Operating Procedures (SOP) for Pump Startup

Electro-Plate's SOP recommends operators to follow the best practices for pump startup proposed by specialists, which vary according to the specific speed of the pump.

For **low to medium specific speed pumps** with flow rates less than 5,000 US gpm, pump startup should occur at **"shut-off condition", where the valve preceding the pump in the pipeline is opened and the valve following the pump is closed** (creating zero flow) to **build up pressure** so fluid can be driven a greater height and distance once the valve following the pump is opened, which will **minimize the initial energy required by the pump driver to overcome frictional and gravitational forces and reduce the cost of electricity** [5].

This **wash system uses a low specific speed pump** and since there is **no valve preceding the pump**, the operator only needs to **keep the valve following the pump (i.e., the inlet valve) closed**

for 30 seconds to start the pump at shut-off condition before gradually fully opening the inlet valve. For centrifugal pumps, like the one used in this pilot study, operating briefly at shut-off condition will increase pump pressure but will not damage the pump However, **prolonged operation above 1 minute at zero flow can cause build-up of heat energy to a dangerous temperature and lead to pump failure** [2].

Electro-Plate's SOP recommends that immediately after pump startup, operators should wait for the wash system to **attain steady state and to maintain this condition for at least 1 minute before further operation**. This duration is the total time required to **fully flush out all potential residues** remaining from the previous shutdown and to **ensure consistency of washing quality**.

Step 1) Ensure the power switch of the pump is turned off. Push the switch downwards to turn off the power.

Step 2) Ensure all 6 valves are fully closed (i.e., inlet, bypass, valve B, diluting, cooling and drainage valves). Ball valves can be closed by turning it 90 degrees to the left. Alternatively, flow control valves can be closed by turning it in a clockwise direction all the way.

PURPOSE: *Fully close inlet valve at pump startup to induce a shut-off condition that can reduce the initial load on the pump driver.*

Step 3) Ensure the water tank is filled and the stopper is placed over the tank inlet.

Step 4) Plug in the pump and sensors' electrical plugs into an electrical outlet. If using an extension cord, ensure the power bar is switched on.

Step 5) Turn on the power switch of the pump by pushing the switch upwards.

Step 6) After 30 seconds, gradually open the inlet valve by turning it 90 degrees to the right.

PURPOSE: *Wait 30 seconds before opening inlet valve to ensure ample pump head is induced to minimize the initial load on the pump driver and reduce cost. Beware that operation at zero flow for over 1 minute can cause pump failure.*

Step 7) Slightly open the diluting and bypass valves by turning them counterclockwise to get rid of the air bubbles in the main pipeline.

Step 8) Check the entire wash system to ensure there are no leakages.

Step 9) Wait for the system to reach steady state, as indicated by a constant inlet flow rate, and maintain this condition for at least 1 minute.

PURPOSE: *Ensure all residues are flushed out and consistency of washing quality.*

PART B: OPERATION OF WASH SYSTEM

Effect of Individual Stream Flows on Inlet Flow Rate

The pump used in this wash system operates at a constant rotational speed and flow rate upon reaching steady state. However, adjustment of valve B and the diluting and cooling valves will cause fluctuations on the inlet flow rate. Specifically, **opening the valves will cause the inlet flow rate to increase** as more water passes through the pipeline at any given time. A greater increase in the inlet flow rate can be achieved by methods such as enabling flow through more streams off the main pipeline, opening valves more, and enabling flow through larger diameter pipes. Thus, to offset fluctuations in inlet flow rate and maintain its value between 19-22 L/min, a **bypass line and its regulating flow control gate valve is used to divert a portion of the excess flow back into the water tank pipeline** such that inlet flow rate can be maintained within the operating criterion range.

Relationship Between Flow Rate and Pressure

Pressure, friction and flow, as depicted in Figure 5, are the 3 main characteristics of a pump system that determine its operation. While pressure acts as the driving force that enables the movement of fluid, friction is the counteracting force that decelerates its movement. The resulting volume of fluid transported per unit time is the system flow rate. The effect of frictional factors can be seen by a decrease in pressure, denoted as pressure loss or pressure drop, along the pipeline. [4]

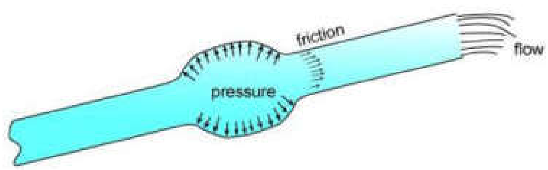

Figure 5 – Effect of Pressure, Friction and Flow in a Pipeline [4]

Within the wash system, there are several locations where the pipeline transitions between larger and smaller diameter pipes. Assuming the wash system is at steady state, flow rate will remain constant across these transitions.

When **transitioning from a larger diameter pipe to a smaller one** as seen in Figure 6, the internal area of the pipe through which fluid flows will decrease. Since flow rate remains constant at steady state, the velocity must increase to offset the difference in pipe diameter. However, **when velocity increases, friction also increases, which causes a decrease in pressure.** [8]

The same principles also apply, where **velocity will decrease and pressure will increase, when transitioning from a pipeline of smaller diameter to one of larger diameter** [8].

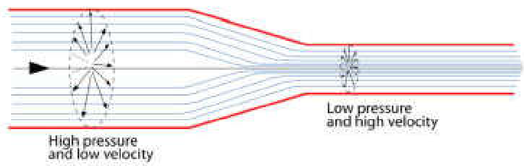

Figure 6 – Transitioning from Higher Diameter to Lower Diameter Pipe [8]

On the contrary, **changes in flow rate do not have an effect on pressure drop**. This is because as changes are made to the flow rate during operation, the pressure changes throughout the entire pipeline. Thus, the overall pressure drop (i.e., difference in pressure between any 2 points on the pipeline) of the system will remain constant.

Pressure Drop

Pressure drop refers to the **difference in pressure between 2 points due to frictional forces acting against fluid flow through the pipeline**. The pump transfers energy to the fluid as pressure which is dissipated to overcome friction. A higher pressure loss can be attributed to greater frictional forces (i.e., longer pipe length through which fluid flows), higher head (i.e., total height to which water is raised), larger quantity of pipe fittings (i.e., elbows, tees and valves), and smaller pipe diameter [1].

Frictional Factors Affecting Pressure Drop

In the wash system, the only **frictional factors affecting pressure loss are pipe length, diameter, head (surface elevation), fittings and direction of flow**. All other pipe and fluid specifications are assumed constant between the various streams. Water flowing through the main pipeline is diverted through a maximum of 4 stream (streams A and B and the diluting and cooling streams), which are the only possible pathways through which water can be returned to the water tank. *NOTE: each of these 4* ***streams considers all frictional forces present from when the stream diverges from the main pipeline to when it is cycled back to the water tank***.

By comparing the frictional forces restricting fluid flow through each of these streams, their effect on the overall system pressure loss can be determined. For instance, to **decrease pressure loss across the system**, operators would need to compare the various streams and adjust certain valves to **increase flow through streams with lesser frictional forces and/or decrease flow through streams with greater frictional forces**. These differences in degree of pressure loss exist between streams due to plant layout, placement of machinery and cost of piping.

The comparison chart shown below (Table 1) lists the distinct differences in frictional factors between fluid flow through each of the 4 streams that affect its pressure drop. In this table, total system head is measured as the fluid's maximum elevation above ground. Bends refer to flow through solid piping, while curves refer to flow through flexible piping. The pipe diameter applies to the entire pipeline used in the specified pathway, except for stream B where 3/8" piping is used for 3 meters of the 3.5-meter-long pathway and 1" piping is used for the remainder. The direction of flow is denoted in brackets, where upwards flow travels against gravity, horizontal flow travels at a constant height, and downwards flow travels in the direction of gravity. Taking into consideration all these factors, assuming the same quantity of fluid is sent through the 4 pathways, the streams sorted **in order of increasing pressure loss are: cooling stream < stream B < diluting stream < stream A**.

Table 1 – Frictional Factors Comparison Chart between Stream Pathways

	Pipe Diameter	**Total System Head**	**Number of Bends**	**Length of Pipe and Direction of Flow**
Stream A to Water Tank	1"	3 m	7 90° bends 1 540° bend 3 90° curves	1.5 m [upwards] 1 m [horizontal] 3 m [downwards] 0.5 m [1 540° bend] **Total: 6 m**
Diluting Stream to Water Tank	1"	2.5 m	9 90° bends 3 90° curves	0.5 m [upwards] 1.5 m [horizontal] 2 m [downwards] **Total: 4 m**
Stream B to Water Tank	3/8" [3 m length] 1" [0.5 m length]	2 m	6 90° bends 2 90° curves 1 180° curve	0.5 m [upwards] 1.5 m [horizontal] 2 m [downwards] **Total: 4 m**
Cooling Stream to Water Tank	1"	2 m	2 90° bend 2 45° bends	1 m [downwards] **Total: 1 m**

Operation Sequence

When operating the wash system, it is essential that operators follow a specific sequence of steps to ensure proper operation of the process while simultaneously maintaining operating criteria.

STEP 1

- **Set stream B to the specified flow rate**.
  - The flow rate of stream B must be set prior to flow rate of Chemical B. This ensures Chemical B, which is a solid, can be transported once it is added to the system.

STEP 2

- **Input mass flow rate of Chemical B onto the control screen**.
  - The flow rate of Chemical B must be inputted prior to Chemical A. B is a solid that will always be filtered through the waste stream. However, A is dissolved in water and will exit through the recycle stream if unreacted with B, contaminating all water in this closed system.

STEP 3

- **Set the diluting stream within the specified flow range**.
  - The flow range of the diluting stream must be set prior to Chemical A. This ensures Chemical A solution can be diluted to a suitable range of concentrations once Chemical A is added to the system to prevent damaging the metal plate or causing runaway reactions.

STEP 4

- **Input mass flow rate of Chemical A onto the control screen**.
  - Since stream A is designed to always have a minimum flow rate of water sufficient to enable formation of Chemical A solution during process operation, there are no controls needed for stream A and Chemical A can be directly added to the stream.

Product Changeover

After each production order is completed, a product changeover will occur where operators thoroughly clean the entire production line in preparation for the next order. During **wash system changeover**, since the chemicals used are the same between production orders, this system only requires a **flush cycle to be run for 1 minute** to be sufficiently cleansed. During changeover, it is **unnecessary to uphold operating criteria as the system is not considered in operation**.

STEP 1:

Set mass flow rates of Chemical A to 0 and Chemical B to 5 g/min to purge the system of all residual impurities and Chemical A.

→

STEP 2:

Fully close cooling and bypass valves (only water flows through these streams so they are considered clean) to force all water through the remaining 3 pathways (i.e., diluting stream, streams A and B).

→

STEP 3:

Open valve B and the diluting valve by an additional 3 rotations to ensure a sufficient flow of water through these streams.

For each new production order that is manufactured, use the information listed in its production notification (refer to notification system on the control screen) to operate the wash system in accordance with the following **general procedure during normal operation**:

Step 1) Turn the cooling valve counterclockwise by 1 rotation to turn on the cooling stream.

> ***PURPOSE:*** *Preventative means to cool down temperature at the reactor exit to prevent build-up of heat to dangerous levels.*

At the same time, simultaneously turn the bypass and cooling valves as needed to maintain inlet flow rate and pressure drop within specified operating criteria range.

> ***PURPOSE:*** *Ensures product quality and operation efficiency standards are satisfied. Note the relationship between operating parameters.*

Step 2) If ***current stream B flow rate < required stream B flow rate***, slowly turn valve B counterclockwise to increase flow rate of flow meter B.
If ***current stream B flow rate > required stream B flow rate***, slowly turn valve B clockwise to decrease flow rate of flow meter B.

> ***PURPOSE:*** ***Order of steps 2-5 is vital** Set before inputting Chemical B to enable its transport once inputted into the system.*

At the same time, simultaneously turn the bypass and cooling valves as needed to maintain inlet flow rate and pressure drop within specified operating criteria range.

> ***PURPOSE:*** *Ensures product quality and operation efficiency standards are satisfied. Note the relationship between operating parameters.*

Step 3) Input the required mass flow rate of Chemical B onto the control screen.

> ***PURPOSE:*** ***Order of steps 2-5 is vital** Inputted prior to Chemical A to ensure that all Chemical A, when added into the system, is removed from the recycle stream* ***via reaction with Chemical B*** *prior to being sent back into the water tank.*

Step 4) If ***current washing stream flow rate < required washing stream flow range***, slowly turn the diluting valve counterclockwise to increase flow rate of flow meter A.
If ***current washing stream flow rate > required washing stream flow range***, slowly turn the diluting valve clockwise to decrease flow rate of flow meter A.

> ***PURPOSE:*** ***Order of steps 2-5 is vital** Set before inputting Chemical A to ensure Chemical A solution is diluted to a suitable concentration once Chemical A is inputted into the system.*

At the same time, simultaneously adjust valve B as needed to maintain flow rate of stream B at the required rate, while also turning the bypass and cooling valves as needed to maintain inlet flow rate and pressure drop within specified operating criteria range.

PURPOSE: *Ensures product quality and operation efficiency standards are satisfied. Note the relationship between operating parameters.*

Step 5) Input the required mass flow rate of Chemical A onto the control screen.

Step 6) Ask the manager (the researcher) to come verify all operating parameters are met.

Step 7) Maintain this condition for 2 minutes.

PURPOSE: *Metal plates are washed in spray bath chamber for only 1 minute (between 00:00:30 and 00:01:30). However, maintaining steady state for 2 minutes (an extra 30 seconds before and after the metal plate enters the spray bath chamber) ensures consistency of Chemical A solution and sufficient coverage of metal plate during chamber entry and exit.*

Step 8) Notify the manager that you have completed the production order.

After the completion of each production order, the entire production line will undergo a **product changeover**. During changeover, operate the wash system in accordance with the following **flush cycle procedure**:

Step 9) Set flow rate of Chemical A to 0 and Chemical B to 5 g/min on the control screen.

PURPOSE: *Stop flow of Chemical A as system is not in operation. Use Chemical B to purge system of all residual Chemical A and impurities.*

Step 10) Flush the system for product changeover for 1 minute while considering that operating criteria **does NOT need to be met**.

PURPOSE: *Flush system for 1 minute to ensure it is sufficiently cleansed. Disregard operating criteria as system is not in operation*

Fully close the cooling and bypass valves by turning them in a clockwise direction all the way. Then, open both valve B and the diluting valve by an additional 3 rotations by turning them in a counterclockwise direction.

PURPOSE: *Open or close the specified valves to force all water through and flush the 3 contaminated stream pathways.*

Step 11) Notify the manager that you have completed the product changeover.

SAMPLE NOTIFICATION ALERTS

< Start Production Order 001 >

<--- PRODUCTION NOTIFICATION --->

Order Number: 001

Metal/Alloy: Copper
Dimensions: 20" (l) x 20" (w) x 1" (h)

	Flow Rate
Chemical A	25 g/min
Chemical B	100 g/min
Washing Stream	9-11 L/min
Stream B	3 L/min

< Completion of Production Order 001 >

<--- PRODUCTION NOTIFICATION --->

Order Number: 001

SHIPPED

Metal/Alloy: Copper
Dimensions: 20" (l) x 20" (w) x 1" (h)

< Product Changeover – Flush Cycle >

PART C: SHUTDOWN OF WASH SYSTEM

Standard Operating Procedures for Pump Shutdown

Electro-Plate's SOP recommends operators to follow the best practices for pump shutdown proposed by specialists, which vary according to the operating specific speed of the pump.

For **low to medium specific speed pumps** with flow rates less than 5,000 US gpm, as in the case of the pump used in this wash system, pump shutdown should occur at **"shut-off condition", where the valve preceding the pump in the pipeline is opened and the valve following the pump is closed** prior to pump shutdown. This would minimize the initial energy required by the pump driver to overcome frictional and gravitational forces so as to reduce costs and prevent backflow through the pump [5].

Electro-Plate's SOP recommends that **prior to pump shutdown**, the wash system undergoes an **additional flush cycle to clear out remaining chemicals or contamination** from the operation. Additionally, during **system drainage after pump shutdown, all valves except draining valve should be fully opened** to ensure proper drainage of all streams back into the water tank.

Step 1) Operate an additional flush cycle of the system for 1 minute.

PURPOSE: *Ensure all remaining chemicals or contamination are flushed out.*

Step 2) Fully close the inlet valve by turning it 90 degrees to the left.

PURPOSE: *Close the inlet valve so pump shutdown occurs at shut-off condition to reduce load on the pump driver and reduce costs.*

Step 3) Ensure the drainage valve remains closed.

Step 4) Turn off the power switch of the pump by pushing the switch downwards.

Step 5) Unplug the pump and sensors' electrical plugs from the electrical outlet. If an extension cord was used, switch off the power bar.

Step 6) Fully open valve B and the inlet, bypass, diluting and cooling valves to cycle all residual water in the system back into the water tank by turning ball valves 90 degrees to the right and flow control valves in a counterclockwise direction all the way.

PURPOSE: *Ensure proper drainage of all streams back into the water tank.*

Step 7) Wait for the water in the main pipeline to fully drain out, then fully close all 5 valves by turning ball valves 90 degrees to the left and flow control valves in a clockwise direction all the way.

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A.3.5 Demographic Survey

<- DEMOGRAPHIC SURVEY ->

Participant ID: __________

Experiment Version: **P** **E**

Part A – Background Information

1. ***What is your age? (please specify)***

   ____

2. ***What is your gender? (please select one)***

   Male Female Trans* Prefer not to disclose Other: ______

3. ***What degree are you currently studying towards? (please select one)***

   Bachelor's Master's Ph.D

4. ***What faculty are you in? (please select one)***

   Applied Health Science Arts Engineering

   Environment Mathematics Science

5. ***What department are you in? (please select one)***

   Accounting and Finance (School of)

   Anthropology

   Applied Language Studies

   Applied Mathematics

   Architecture (School of)

   Balsillie School of International Affairs (Global Governance)

   Biochemistry

   Biology

   Biomedical Engineering

   Chemical Engineering

   Chemistry

   Civil Engineering

   Classical Studies

   Combinatorics and Optimization

   Computer Engineering

Computer Science (David R. Cheriton School of)

Drama and Speech Communication

Earth and Environmental Sciences

East Asian Studies

Economics

Electrical Engineering

English Language and Literature

English Language Institute (Renison ELI)

Environment, Enterprise and Development (School of)

Environment, Resources and Sustainability (School of)

Environmental Engineering

Fine Arts

French Studies

Geography and Environmental Management

Germanic and Slavic Studies

History

Kinesiology

Management Sciences

Masters of Public Service

Mechanical Engineering

Mechatronics Engineering

Music

Optometry and Vision Science (School of)

Peace and Conflict Studies

Pharmacy (School of)

Philosophy

Physics and Astronomy

Planning (School of)

Political Science

Psychology

Public Health and Health Systems (School of)

Pure Mathematics

Recreation and Leisure Studies

Religious Studies

Science and Business

Social Work (School of)

Sociology and Legal Studies

Statistics and Actuarial Science

Systems Design Engineering

Theological Studies

6. What year are you in for your current program? (please select one)

1 2 3 4 5 6+

Part B – Usage of Manual

For each of the following questions, select the answer that best matches your response.

7. ***Have you ever read a training manual or an instruction manual?***

   Yes No

8. ***On average, how much of manuals do you generally read?***

None	Little	Some	Most	All
1	2	3	4	5

9. ***On average, how much information in manuals do you find useful and generally use?***

None	Little	Some	Most	All
1	2	3	4	5

10. ***On average, to what extent do you follow procedures listed in manuals?***

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

11. ***How fluent are you in the English language in terms of reading comprehension?***

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

Part C – Past Experiences

For each of the following questions, select the answer that best matches your response.

1. ***How much hands-on experience do you have manually operating a pump system (i.e., equipment in this experiment) in an industrial or laboratory setting?***

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

2. ***How much hands-on experience do you have manually adjusting a valve (i.e., ball valves and flow control valves used in this experiment) in an industrial or laboratory setting?***

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

3. ***How much theoretical knowledge do you have of basic fluid mechanic principles (i.e., effects of and relationships between pressure, pressure loss and flow rate)?***

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

4. ***How much hands-on experience do you have applying basic fluid mechanic principles (i.e., effects of and relationships between pressure, pressure loss and flow rate) to an operation in an industrial or laboratory setting?***

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

5. ***How often have you used a manual to self-teach yourself how to operate an industrial or laboratory system?***

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

A.3.6 Questionnaire

<- QUESTIONNAIRE ->

Participant ID: ________

Experiment Version: P E

Questionnaire Version: 1 2 3

For each of the following questions, select the answer that best matches your response. Please be as accurate as possible when answering. However, if you really have no idea what the answer is to a question, please select the "I don't know" option rather than making a random guess.

Part 1 – Understanding of Wash System

1. What is the purpose of the wash system?

a) Thoroughly cleanse metal plates under a spray bath of Chemical A solution to remove impurities prior to electroplating
b) Thoroughly cleanse metal plates under a spray bath of Chemical A solution to remove residues following electroplating
c) Thoroughly rinse metal plates with water to remove impurities prior to electroplating
d) Thoroughly rinse metal plates with water to remove residues following electroplating
e) I don't know

2. Where are the real-time data readings for inlet flow rate and pressure loss displayed?

a) Respectively on the inlet flow meter and the pressure sensors on the system
b) Respectively on the inlet flow rate graph on the control screen and on the pressure sensors on the system
c) Respectively on the inlet flow rate graph and display, and the pressure loss graph and display on the control screen
d) There are no data readings for these parameters. Instead, an alarm will light up on the control screen if these parameters fall beyond the operating criteria range
e) I don't know

3. Which of the following is NOT an operating criterion?

a) Maintain an inlet flow rate within the range of 19 to 22 L/min
b) Maintain a pressure drop less than 4 psi across the wash system
c) Maintain temperature at reactor exit below the critical temperature of 80 °C
d) Complete changes made to the system as quickly as possible
e) I don't know

4. What type of pump is used in the wash system?

a) Centrifugal pump
b) Positive displacement pump
c) Screw pump
d) Piston pump
e) I don't know

5. What type of valve is used as the cooling valve?

a) Ball valve
b) Check valve
c) Flow control valve
d) Rotary valve
e) I don't know

6. What type of valve is used as the inlet valve?

a) Ball valve
b) Check valve
c) Flow control valve
d) Rotary valve
e) I don't know

Part 2 – Understanding of Technical and Safety Knowledge

7. How is spent water purified prior to being recycled back into the water tank?

a) Chemical A and the impurities in the spent water aggregate onto Chemical B, which is a solid, and are filtered in the reactor and discharged through the waste stream
b) Chemical A and the impurities in the spent water are all solids that are filtered in the reactor and discharged through the waste stream
c) Spent water is not purified but discharged through the waste stream; there is an external water stream that replenishes the wash system with clean water
d) Chemical A and the impurities are broken down by Chemical B such that the spent water becomes purified
e) I don't know

8. What is an exothermic reaction?

a) A process that absorbs heat from its surroundings during the reaction
b) A process that releases heat into its surroundings during the reaction
c) A process that neither absorbs nor releases heat during the reaction
d) A process that alternates between absorbing and releasing heat during the reaction
e) I don't know

9. At Electro-Plate, how long does the emergency response standard advise operators to wait before implementing an emergency stop in response to overheating?

a) 1 minute
b) 2 minutes
c) 3 minutes
d) 5 minutes
e) I don't know

10. Is it necessary for the cooling stream to always be running during process operation?

a) Yes, it acts as a preventative means to inhibit the accumulation of heat from the exothermic reactions above the critical temperature.
b) Yes, it must be adjusted to a certain flow rate to maintain inlet flow rate and pressure drop within the operating criteria range.
c) No, the cooling valve can be kept closed during operation. It only needs to be opened during product changeover when the wash system is flushed.
d) No, the temperature of the reactor is usually maintained within an acceptable range. Usage of the cooling stream is only required if the alarm lights up.
e) I don't know

11. Why must the temperature at reactor exit NOT exceed the critical temperature of 80 °C?

a) Waste precipitate become highly flammable at temperatures above 80 °C
b) Pipeline becomes highly susceptible to ruptures above temperatures of 80 °C
c) All of the above
d) None of the above
e) I don't know

12. What is the relationship between flow rate and pressure (i.e., inlet flow rate and pressure 1)?

a) Flow rate and pressure are not related
b) An increase in flow rate causes an increase in pressure
c) An increase in flow rate causes a decrease in pressure
d) An increase in flow rate causes a decrease in pressure but an increase in pressure may not necessarily cause a decrease in flow rate
e) I do not know

13. Which of the following is FALSE regarding pressure drop?

a) Pressure drop is the difference in pressure between 2 points in a system
b) Pressure drop will always exist across a pipeline
c) Pressure drop is caused by frictional forces acting as a resistance to flow
d) Pressure drop is affected by changes in flow rate
e) I don't know

14. Which of the following is true regarding the bypass stream?

a) Diverts a portion of the flow back into the water tank pipeline to regulate the inlet flow rate
b) Bypasses all stream processes in the water system
c) All of the above
d) None of the above
e) I don't know

15. What are the benefits of a flow control valve compared to a ball valve?

a) Handle only needs to be turned 90 degrees to fully enable or restrict flow through the pipe
b) Provides greater precision in controlling the flow rate through the pipe
c) All of the above
d) None of the above
e) I don't know

Part 3 – Operation and Scenario Performance

16. How would you increase flow through a pipe that is restricted by a ball valve?

a) Turn the valve up to 90 degrees to the right
b) Turn the valve up to 90 degrees to the left
c) Turn the valve in a clockwise direction (maximum of several rotations)
d) Turn the valve in a counterclockwise direction (maximum of several rotations)
e) I don't know

17. How would you decrease flow through a pipe that is restricted by a flow control valve?

a) Turn the valve up to 90 degrees to the right
b) Turn the valve up to 90 degrees to the left
c) Turn the valve in a clockwise direction (maximum of several rotations)
d) Turn the valve in a counterclockwise direction (maximum of several rotations)
e) I don't know

18. What is the operating procedure for pump startup and shutdown in the wash system?

a) Both the valves preceding and following (i.e., inlet valve) the pump are closed
b) The valve preceding the pump is closed and the valve following the pump (i.e., inlet valve) is opened
c) The valve preceding the pump is opened and the valve following the pump (i.e., inlet valve) is closed
d) Both the valves preceding and following (i.e., inlet valve) the pump are opened
e) I don't know

19. What is the proper sequence of steps, as shown in the manual, to operate the wash system?

a) Input mass flow rate of Chemical A → Input mass flow rate of Chemical B → Set stream B within flow range → Set washing stream to specified flow rate
b) Input mass flow rate of Chemical A → Set stream B within flow range → Input mass flow rate of Chemical B → Set washing stream to specified flow rate
c) Set stream B within flow range → Set washing stream to specified flow rate → Input mass flow rate of Chemical A → Input mass flow rate of Chemical B
d) Set stream B within flow range → Input mass flow rate of Chemical B → Set washing stream to specified flow rate → Input mass flow rate of Chemical A
e) I don't know

20. During process operation, if the inlet flow rate is 20 L/min and pressure drop is 1.5 psi, which of parameters require adjustment to be within the operating criteria range?

a) Inlet flow rate
b) Pressure drop
c) Both inlet flow rate and pressure drop
d) Neither, they are both within the operating criteria range
e) I don't know

21. While operating the wash system, the inlet flow rate increased to 24 L/min while the pressure drop remained within the operating criteria range. Which of the following can be done to decrease inlet flow rate to within the range of 19-22 L/min?

a) Turn inlet valve counterclockwise
b) Turn bypass valve counterclockwise
c) Turn diluting valve counterclockwise
d) Turn cooling valve counterclockwise
e) I don't know

22. While operating the wash system, the pressure drop increased to 5 psi while the inlet flow rate remained within the operating criteria range. Which of the following can be done to decrease pressure drop to below 4 psi?

a) Turn inlet valve counterclockwise
b) Turn bypass valve clockwise
c) Turn diluting valve clockwise
d) Turn cooling valve counterclockwise
e) I don't know

23. Why must the mass flow rates of Chemical A and B be set to 0 during the emergency stop of the production line if overheating persists beyond 2 minutes?

a) Prevent any further reactions from occurring in the reactor
b) Stop flow rate through stream B and the washing stream so there is no input into reactor
c) Enable usage of stream B and the washing stream as cooling streams
d) Both a) and c) are correct
e) I don't know

24. If pressure loss is above the operating criteria range, how would opening the 4 stream pathways rank in terms of increasing effectiveness to reduce pressure loss?

a) Cooling Stream > Stream B > Diluting Stream > Stream A
b) Cooling Stream > Diluting Stream > Stream B > Stream A
c) Stream A > Stream B > Diluting Stream > Cooling Stream
d) Stream A > Diluting Stream > Stream B > Cooling Stream
e) I don't know

25. Which of the following combinations of frictional factors causes the diluting stream to have a greater resistance to flow compared to stream B?

a) Pipe diameter, total system head, number of bends
b) Total system head, length of pipe, direction of flow
c) Pipe diameter, number of bends
d) Pipe diameter, number of bends, direction of flow
e) I don't know

A.3.7 Questionnaire Solution

<- QUESTIONNAIRE SOLUTION->

Project Title:	**Effect of Training Methods on Operation and Understanding of a Hydraulic Pump System**
Student Investigator:	**Keziah Chan, Department of Systems Design Engineering, humanfactors.uwaterloo@gmail.com**
Faculty Advisors:	**Shi Cao, Department of Systems Design Engineering, shi.cao@uwaterloo.ca, 519-888-4567 x36377**
	Ali Elkamel, Department of Chemical Engineering, aelkamel@uwaterloo.ca, 519-888-4567 x37157

Part A – Understanding of Wash System

1. ***What is purpose of the wash system?***

   ANSWER: Thoroughly cleanse metal plates under a spray bath of Chemical A solution to remove impurities prior to electroplating

2. ***Where are the real-time data readings for inlet flow rate and pressure loss displayed?***

   ANSWER: Respectively on the inlet flow rate graph and display, and the pressure loss graph and display on the control screen

3. ***Which of the following is NOT an operating criterion?***
   ANSWER: Maintain temperature at reactor exit below the critical temperature of 80 °C

4. ***What type of pump is used in the wash system?***
   ANSWER: Centrifugal pump

5. ***What type of valve is used as the cooling valve?***
   ANSWER: Flow control valve

6. ***What type of valve is used as the inlet valve?***
   ANSWER: Ball valve

Part B – Understanding of Technical and Safety Knowledge

7. ***How is spent water purified prior to being recycled back into the water tank?***
   ANSWER: Chemical A and the impurities in the spent water aggregate onto Chemical B, which is a solid, and are filtered in the reactor and discharged through the waste stream

8. ***What is an exothermic reaction?***
   ANSWER: A process that releases heat into its surroundings during the reaction

9. ***At Electro-Plate, how long does the emergency response standard advise operators to wait before implementing an emergency stop in response to overheating?***
   ANSWER: 2 minutes

10. ***Is it necessary for the cooling stream to always be running during process operation?***
    ANSWER: Yes, it acts as a preventative means to inhibit the accumulation of heat from the exothermic reactions above the critical temperature.

11. ***Why must the temperature at reactor exit NOT exceed the critical temperature of 80 °C.***
    ANSWER: None of the above (Waste precipitate become highly flammable at temperatures above 80 °C; Pipeline becomes highly susceptible to ruptures above temperatures of 80 °C)

12. ***What is the relationship between flow rate and pressure (i.e., inlet flow rate and pressure 1)?***
    ANSWER: An increase in flow rate causes a decrease in pressure

13. ***Which of the following is FALSE regarding pressure drop?***
    ANSWER: Pressure drop is affected by changes in flow rate

14. ***Which of the following is true regarding the bypass stream?***
    ANSWER: All of the above (Diverts a portion of the flow back into the water tank pipeline to regulate the inlet flow rate; Bypasses all stream processes in the water system)

15. ***What are the benefits of a flow control valve compared to a ball valve?***
    ANSWER: Provides greater precision in controlling the flow rate through the pipe

Part C – Operation and Scenario Performance

16. How would you increase flow through a pipe that is restricted by a ball valve?

ANSWER: Turn the valve up to 90 degrees to the right

17. How would you decrease flow through a pipe that is restricted by a flow control valve?

ANSWER: Turn the valve in a clockwise direction (maximum of several rotations).

18. What is the operating procedure for pump startup and shutdown in the wash system?

ANSWER: The valve preceding the pump is opened and the valve following the pump (i.e., inlet valve) is closed

19. What is the proper sequence of steps, as shown in the manual, to operate the wash system?

ANSWER: Set stream B within flow range → Input mass flow rate of Chemical B → Set washing stream to specified flow rate → Input mass flow rate of Chemical A

20. During process operation, if the inlet flow rate is 20 L/min and pressure drop is 1.5 psi, which of parameters require adjustment to be within the operating criteria range?

ANSWER: Neither, they are both within the operating criteria range

21. While operating the wash system, the inlet flow rate increased to 24 L/min while the pressure drop remained within the operating criteria range. Which of the following can be done to decrease inlet flow rate to within the range of 19-22 L/min?

ANSWER: Turn bypass valve counterclockwise

22. While operating the wash system, the pressure drop increased to 5 psi while the inlet flow rate remained within the operating criteria range. Which of the following can be done to decrease pressure drop to below 4 psi?

ANSWER: Turn cooling valve counterclockwise

23. Why must the mass flow rates of Chemical A and B be set to 0 during the emergency stop of the production line if overheating persists beyond 2 minutes?

ANSWER: Both a) and c) are correct (Prevent any further reactions from occurring in the reactor; Enable usage of stream B and the washing stream as cooling streams)

24. If pressure loss is above the operating criteria range, how would opening the 4 stream pathways rank in terms of increasing effectiveness to reduce pressure loss?

ANSWER: Cooling Stream > Stream B > Diluting Stream > Stream A

25. Which of the following combinations of frictional factors causes the diluting stream to have a greater resistance to flow compared to stream B?

ANSWER: Pipe diameter, total system head, number of bends

A.3.8 Practicality Survey

<- PRACTICALITY SURVEY ->

Participant ID: _________

Experiment Version:

P	**Complete Questions 1 to 5**
E	**Complete Questions 1 to 8**

Part A

Answer the following questions with respect to the overheating emergency response task.

a) Prior to the production line emergency stop, how did you manipulate the wash system controls (i.e., valves and flow rates) and what subgoals were you aiming to achieve?

b) After the production line emergency stop, what procedure did you formulate to lower the temperature at the reactor exit and reduce overheating?

c) What is the rationality behind this procedure?

d) How did you manipulate the wash system controls (i.e., valves and flow rates) to achieve this?

e) What problems or issues did you encounter and how did you resolve them?

Part B

Answer the following questions with respect to both the normal operation and emergency response tasks.

a) How many valves did you generally manipulate simultaneously? Are there any reasons why?

b) What problem solving approaches did you use to operate the system?

c) Did you develop or use any procedures not included in the manual to aid your operation?

d) Did your operation of the system change over time? How did it change?

e) Was it easy to remember which way to turn the valve in order to achieve a certain change in parameter? Was there anything you did to help you remember?

f) Did you adhere to ALL the waiting times stated in the training manual? Why?

g) Did you adhere to the sequence of steps stated in the training manual? Why?

h) Which would you prefer? Having only the information on the procedure to operate the wash system or in addition, having background information to explain ow the wash system works?

i) Is there anything else you would like to tell us about your experience in this experiment?

Part C

Answer the following questions with respect to your understanding of the overall operation after using the training manual.

a) How useful did you find the training manual?

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

b) To what extent did you understand what was happening during regular operation of the case study?

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

c) To what extent did you understand which steps you should undertake in response to different production orders?

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

d) To what extent did you understand why an emergency arose?

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

e) To what extent did you understand which steps were appropriate and should be undertaken in response to the emergency scenario?

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

Part D

Answer the following questions with respect to the step-by-step instructions provided throughout the training manual.

a) How much did you read?

None	Little	Some	Most	All
1	2	3	4	5

b) How much did you understand?

None	Little	Some	Most	All
1	2	3	4	5

c) How applicable and useful did you find the information?

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

d) To what extent did you follow the procedures listed in the manual?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

e) To what extent did you feel that the information improved your understanding of the process operation?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

f) To what extent did you feel that the information improved your accuracy and speed of operating the pump system?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

Part E

Answer the following questions in regards to the <Introduction> section of the training manual. This includes the following sections:

- ***About Electro-Plate Inc.***
- ***Electroplating Process***
- ***Wash System***
- ***Chemical A and Chemical B***
- ***Overheating***
- ***Operating Criteria***
- ***Production Notifications and Operation Alerts***

a) How much did you read?

None	Little	Some	Most	All
1	2	3	4	5

b) How much did you understand?

None	Little	Some	Most	All
1	2	3	4	5

c) How applicable and useful did you find the information?

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

d) To what extent did you feel that the information increased your adherence to following the procedures listed in the manual?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

e) To what extent did you feel that the information improved your understanding of the process operation?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

f) ***To what extent did you feel that the information improved your accuracy and speed of operating the pump system?***

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

g) ***To what extent did you feel that the information aided you in understanding and responding appropriately to the emergency response task?***

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

h) ***Overall, how essential did you feel this section was to your understanding and operation of the system?***

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

Part F

Answer the following questions with respect to the background information provided at the beginning of Part A of the training manual, which includes the following sections:

- ***Operation of Valves***
- ***Standard Operating Procedures (SOP) for Pump Startup***

a) How much did you read?

None	Little	Some	Most	All
1	2	3	4	5

b) How much did you understand?

None	Little	Some	Most	All
1	2	3	4	5

c) How applicable and useful did you find the information?

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

d) To what extent did you feel that the information increased your adherence to following the procedures listed in the manual?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

e) To what extent did you feel that the information improved your understanding of the process operation?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

f) To what extent did you feel that the information improved your accuracy and speed of operating the pump system?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

g) Overall, how essential did you feel this section was to your understanding and operation of the system?

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

Part G

Answer the following questions with respect to the background information provided at the beginning of Part B of the training manual, which includes the following sections:

- ***Effect of Individual Stream Flows on Inlet Flow Rate***
- ***Relationship Between Flow Rate and Pressure***
- ***Pressure Drop***
- ***Frictional Factors Affecting Pressure Drop***
- ***Operation Sequence***
- ***Product Changeover***

a) How much did you read?

None	Little	Some	Most	All
1	2	3	4	5

b) How much did you understand?

None	Little	Some	Most	All
1	2	3	4	5

c) How applicable and useful did you find the information?

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

d) To what extent did you feel that the information increased your adherence to following the procedures listed in the manual?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

e) To what extent did you feel that the information improved your understanding of the process operation?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

f) To what extent did you feel that the information improved your accuracy and speed of operating the pump system?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

g) To what extent did you feel that the information aided you in understanding and responding appropriately to the emergency response task?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

h) Overall, how essential did you feel this section was to your understanding and operation of the pump system?

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

Part H

Answer the following questions with respect to the background information provided at the beginning of Part C of the training manual, which includes the following section:

- ***Standard Operating Procedures for Pump Shutdown***

a) How much did you read?

None	Little	Some	Most	All
1	2	3	4	5

b) How much did you understand?

None	Little	Some	Most	All
1	2	3	4	5

c) How applicable and useful did you find the information?

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

d) To what extent did you feel that the information increased your adherence to following the procedures listed in the manual?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

e) To what extent did you feel that the information improved your understanding of the process operation?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

f) To what extent did you feel that the information improved your accuracy and speed of operating the pump system?

None	Little	Somewhat	Considerable	Substantial
1	2	3	4	5

*g) **Overall, how essential did you feel this section was to your understanding and operation of the pump system?***

Not at all	Slightly	Somewhat	Considerably	Extremely
1	2	3	4	5

A.3.9 Control Screen Notifications

Wash System Notification Screen

<--- PRODUCTION NOTIFICATION --->

Order Number: 001

Metal/Alloy: Copper
Dimensions: 20" (l) x 20" (w) x 1" (h)

	Flow Rate
Chemical A	25 g/min
Chemical B	100 g/min
Washing Stream	9-11 L/min
Stream B	3 L/min

<--- PRODUCTION NOTIFICATION --->

Order Number: 001

SHIPPED

Metal/Alloy: Copper
Dimensions: 20" (l) x 20" (w) x 1" (h)

Implement a Product Changeover (Flush Cycle)

<--- PRODUCTION NOTIFICATION --->

Order Number: 002

Metal/Alloy: Zinc
Dimensions: 5" (l) x 5" (w) x 2" (h)

	Flow Rate
Chemical A	35 g/min
Chemical B	150 g/min
Washing Stream	8-10 L/min
Stream B	2 L/min

<--- PRODUCTION NOTIFICATION --->

Order Number: 002

SHIPPED

Metal/Alloy: Zinc
Dimensions: 5" (l) x 5" (w) x 2" (h)

Implement a Product Changeover (Flush Cycle)

<--- PRODUCTION NOTIFICATION --->

Order Number: 003

Metal/Alloy: Nickel
Dimensions: 15" (l) x 10" (w) x 1" (h)

	Flow Rate
Chemical A	15 g/min
Chemical B	80 g/min
Washing Stream	10-12 L/min
Stream B	3 L/min

<--- PRODUCTION NOTIFICATION --->

Order Number: 003

SHIPPED

Metal/Alloy: Nickel
Dimensions: 15" (l) x 10" (w) x 1" (h)

Implement a Product Changeover (Flush Cycle)

<--- PRODUCTION NOTIFICATION --->

Order Number: 004 ***CUSTOMIZED ORDER***

Metal/Alloy: 30% Chromium, 30% Lead, 40% Iron
Dimensions: 20" (l) x 15" (w) x 5" (h)

	Flow Rate
Chemical A	50 g/min
Chemical B	550 g/min
Washing Stream	9-11 L/min
Stream B	4 L/min

<--- PRODUCTION NOTIFICATION --->

Order Number: 004 *****CUSTOMIZED ORDER*****

Metal/Alloy: 30% Chromium, 30% Lead, 40% Iron
Dimensions: 20" (l) x 15" (w) x 5" (h)

	Flow Rate
Chemical A	50 g/min
Chemical B	550 g/min
Washing Stream	9-11 L/min
Stream B	4 L/min

~~~ OPERATION ALERT ~~~

OVERHEATING: Exit Reactor Temperature > Critical Temperature

Procedure:

- Lower temperature at reactor exit as quickly as possible by maximizing flow rate through the cooling stream.
- Maintain operation at specified mass flow rates of Chemical A and B, as well as within specified flow range of washing stream and at flow rate of stream B.
- ***Low Priority*** Maintain inlet flow rate and pressure drop within operating criteria range.

If overheating persists over 2 minutes,

- Set mass flow rates of Chemical A and B to 0.
- Lower temperature at reactor exit as quickly as possible using any combination of controls and streams for cooling purposes. Disregard operating criteria.

A.3.10 Adherence Checklist

CHECKLIST					
Part A	Procedure				
	S6: Wait 30 s				
	S9: Wait 1 min				
Part B		Order 001	Order 002	Order 003	Order 004
Order	Procedure				
	S7: Wait 2 mins				
Changeover	Procedure				N/A
	S10: Wait 1 min				N/A
Emergency	Instructions				
	Wait 2 mins				
Part C					
Changeover	Procedure				
	S1: Wait 1 min				
Shutdown	Procedure				

A.3.11 Feedback Letter

UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING
Department of Systems
Design Engineering

FEEDBACK LETTER

Project Title:	**Effect of Training Methods on Operation and Understanding of a Hydraulic Pump System**
Student Investigator:	**Keziah Chan, Department of Systems Design Engineering, humanfactors.uwaterloo@gmail.com**
Faculty Advisors:	**Shi Cao, Department of Systems Design Engineering, shi.cao@uwaterloo.ca, 519-888-4567 x36377**
	Ali Elkamel, Department of Chemical Engineering, aelkamel@uwaterloo.ca, 519-888-4567 x37157

We appreciate your participation in our study and thank you for spending the time helping us with our research!

In this study, you were given either a procedural or an explanatory instruction manual and asked to adjust hydraulic pump system parameters following training instructions in an industrial case study. The purpose of this study was to compare the effects of using a procedural instruction manual that only tells users what they need to do verses using an explanatory instruction manual that tells users both what and why they need to do something, and determining whether the latter will improve user accuracy, speed, understanding of underlying principles and adherence to instructions listed in manual. In this case, the study examined your accuracy in meeting operating criteria (maintaining inlet flow rate and pressure drop within a specified range), speed of completing each task, and degree of process operation and concepts learned and retained over a 14-day period (survey responses and test scores). Additionally, we were interested in observing your emergency response performance where you are asked to execute a series of steps similar to those in the previous 3 tasks but with limited guidance to cool down the system to prevent overheating. As you probably observed, the scenarios in this experiment were entirely made up and no reactions or overheating occurred at any point in time. Your operation of the system was observed and noted by the researcher for comparison purposes to examine whether instructions were followed (especially steps that appear redundant or unnecessary) and general operation patterns and techniques used.

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UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING
Department of Systems
Design Engineering

This study was conducted with partial disclosure of the contents of the research project. The reason that we needed to use partial disclosure was because we needed participants' behavior and attitudes to be as natural as possible. Thus, we could not give participants complete information before their involvement in the study because it may have influenced their behaviour in a way that would make investigations of the research question invalid. If participants knew the objectives of the study beforehand, their behaviour and attitudes may have been influenced by this knowledge. However, I would like to assure you that most engineering research does not involve the use of deception.

As this study involved some aspects that you were not told about before starting, it is very important that you not discuss your experiences or disclose this feedback letter to any other students who potentially could be in this study until after the end of the term. If people come into the study knowing about our specific predictions, as you can imagine, it could influence their results, and the data we collect would not be useable.

All information you provided is considered completely confidential; your name will not be included or in any other way associated with the data collected in the study. Furthermore, because the interest of this study is in the average responses of the entire group of participants, you will not be identified individually in any way in any written reports of this research. Paper records of data will be retained in a locked filing cabinet while electronic data files will be stored on a secure laptop within a locked cabinet in EC4 2127, to which only researchers associated with this study will have access, and confidentially shredded after being retained for 5 years. All identifying information will be removed from the data records prior to storage.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE 21951). In the event you have any comments or concerns resulting from your participation in this study, please contact the Chief Ethics Officer, Office of Research Ethics, at 1-519-888-4567, ext. 36005 or ore-ceo@uwaterloo.ca.

If you think of any other questions regarding this study, please do not hesitate to contact Keziah Chan.

We really appreciate your participation and hope that this has been an interesting experience for you.

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