MASTER THESIS
EDUCATIONAL PSYCHOLOGY

Educational design recommendations to improve the training programme for new operators of pyrolysis plants.

Rebeca Indira
S2669080
University of Twente

Primary supervisor: Mohammadreza Farrokhnia
Second supervisor: Marieke van Geel
Date: 25 February 2024
Word count: 14,848

ABSTRACT

This research report explores the challenges encountered by BTG Bioliquids (BTL) in the effort to enhance their new operators’ training program. The study aims to offer educational design recommendations by addressing existing gaps in the current training programme and aligning them with BTL's strategic goals and operators' learning needs. Utilising McKenney and Reeves' (2018) generic model for conducting design research in education, the project conducts a comprehensive review, design, and pilot implementation of design recommendations for new operators’ training programme. **Analysis.** This research investigates the current training landscape by gathering insights from key stakeholders, examining the structural and operational aspects of the training, and identifying design boundaries. Findings revealed key areas for improvement, such as the need to activate prior knowledge, refine the curation of training content and assessment methods, establish a structured support system, and maximise the utilisation of online and technology-supported learning. **Design.** The design process was guided by Van Merriënboer and Kirschner's (2017) four-component instructional design (4C/ID) model. Initial design propositions include the creation of a comprehensive training framework, the development of trainers' guidelines, and the integration of online learning methods where applicable. **Evaluation.** A pilot implementation of the recommended design showed promising results, with stakeholders favouring the proposed design. However, further iterations and complete module development are needed to fully assess the recommendations' effectiveness. Overall, this research underscores the significance of applying sound instructional design principles to address real-world training challenges effectively.

Keywords: educational design research, four-component instructional design, 4C/ID, operator education, biofuel plant operator training

TABLE OF CONTENTS

ABSTRACT **1**
TABLE OF CONTENTS **2**
1. INTRODUCTION **5**
1.1 Problem Statement 5
1.2 Subject Background 5
1.3 Relevant Stakeholders 7
1.3.1 BTL 7
1.3.2 The Trainers 7
1.3.3 Client Management 8
1.3.4 The Trainees 8
1.4 Research Objective and Research Questions 8
2. DESIGN APPROACH **9**
2.1 Analysis and Exploration 9
2.2 Design and Construction 10
2.3 Evaluation and Reflection 10
3. ANALYSIS AND EXPLORATION **11**
3.1 Data Collection 11
3.1.1 The Trainers 11
3.1.2 The Trainees 12
3.1.3 Data Processing 13
3.2 Retrieved Contextual Information 14
3.2.1 Current-State Training Initiatives 14
3.2.2 Plant Operators' Daily Obligations 15
3.3 Identified Areas of Improvement 16
3.3.1 Novel information and its implication 16
3.3.2 Classroom Training Content 17
3.3.3 Classroom Training Assessment & Exercise 21
3.3.4 Operators Dependency 22
3.3.5 Training Methods and Tools 23
3.4 Identified Design Boundaries 24
3.4.1 Available Technology 24
3.4.2 Trainers 24
3.4.3 Past Experiences & Documentation 25

3.4.4 Operators' Background 25
3.4.5 Relations Between BTL and Its Clients 26
3.5 Initial Design Prepositions 26
4. DESIGN AND CONSTRUCTION 27
4.1 4C/ID Model 27
4.1.1 Learning Tasks (LTs) 28
4.1.2 Supportive Information 28
4.1.3 Procedural Information 29
4.1.4 Part-Task Practice 29
4.2 Design Process - 4C/ID Model 29
4.2.1 Step 1. Design LTs 30
4.2.2 Step 2: Design Performance Assessment 30
4.2.3 Step 3: Sequence LTs 31
4.2.4 Step 4: Design Supportive Information 32
4.2.5 Step 5 & 6: Analyse Cognitive Strategies & Mental Models 33
4.2.6 Step 7: Design Procedural Information 33
4.2.7 Step 8 & 9: Analyse Cognitive Rules and Prerequisite Knowledge 33
4.2.8 Step 10: Design Part-Task Practice 33
4.3 Product Description and Justification 33
4.3.1 Design Guideline for Online Pre-Training Package 34
4.3.2 Design Guideline for Classroom Training 35
4.3.3 On-the-job Training Checklist Template 36
4.3.4 Trainers' Guideline 37
5. EVALUATION AND REFLECTION 38
5.1 Evaluation - Pilot Training 38
5.2 Participants 38
5.3 Pilot Training Module Creation Methodology 38
5.3.1 Learners Need Analysis 39
5.3.2 Design Boundaries Analysis 39
5.3.3 LT Analysis, Learning Objective Identification, Task Structuring 39
5.3.4 Content Analysis 40
5.5.5 Learning Mode Analysis 41
5.5.6 Content Creation 41
5.6 Pilot Training Implementation Procedure 45
5.7 Pilot Training - Result 46

5.7.1 Operators' Performance 47
5.7.2 Operators' Learning Experience 48
5.7.3 BTL Training Team Learning Experience 48
5.8 Pilot Training - Conclusion 49
5.8.1 Lessons Learned for Future Implementation 49
5.9 Process Reflection 50
5.10 Product Reflection 51
Reference 52
Appendix A Operators Analysis Survey Questions 58
Appendix B Codes and Variations of the New operators' training's Problem Areas 62
Appendix C Expected Ideal Performance for New Operators 65
Appendix D Design Guideline for Online Pre-Training 66
Appendix E Design Guideline for Classroom Training 71
Appendix F On-the-job Training Checklist Template 90
Appendix G Trainers' Guideline 92
Appendix H Pilot Trainers' Guideline 96
Appendix I Performance Assessment Rubric for Pilot Training Implementation 99

1. INTRODUCTION

1.1 Problem Statement

Plant operators play a vital role in ensuring the seamless operation of industrial facilities. As such, an effective training programme for plant operators is essential for their safety and the company's overall success. The quality of their training can often be the difference between a well-functioning plant and one riddled with operational setbacks, with the added risk of accidents and legal or financial repercussions (Chryssolouris, 2006). Beyond plant operations, effective operator training also rides the balance of having to align with the strategic goals and competency demands of both the training providers and plant owners (Stadnicka et al., 2019). Thus, the challenge lies in maintaining training efficacy while accommodating industry growth, reducing costs, and adjusting to the design boundaries presented by the key stakeholders.

Even when dealing with inherently intuitive equipment and procedures, the importance of comprehensive education of plant operators cannot be overstated (Chryssolouris, 2006; Skiba, 2020). This need becomes even more critical when the technology and processes within the plant can be considered as novel in their respective fields. This sets the stage for the challenges faced by the subject of this thesis project as they aim to improve their operators' training programme.

1.2 Subject Background

The subject of this design research is BTG Bioliquids (referred to as BTL from now on), a Netherlands-based engineering company that specialises in providing technology for sustainable energy solutions. They are the pioneers of fast pyrolysis technology, which is a process that converts biomass and waste materials into renewable biofuels and biochemicals (see Figure 1 for an illustration of the pyrolysis process). Their dedication to research and development positions them as key players in addressing global climate change and resource conservation challenges. Their business model revolves around selling fast pyrolysis technology to prospective buyers. This requires their active involvement in the plant commissioning process, where they work closely with their client buyer and a third-party company to construct pyrolysis plants. See Figure 2 for an exterior picture of a commissioned pyrolysis plant.

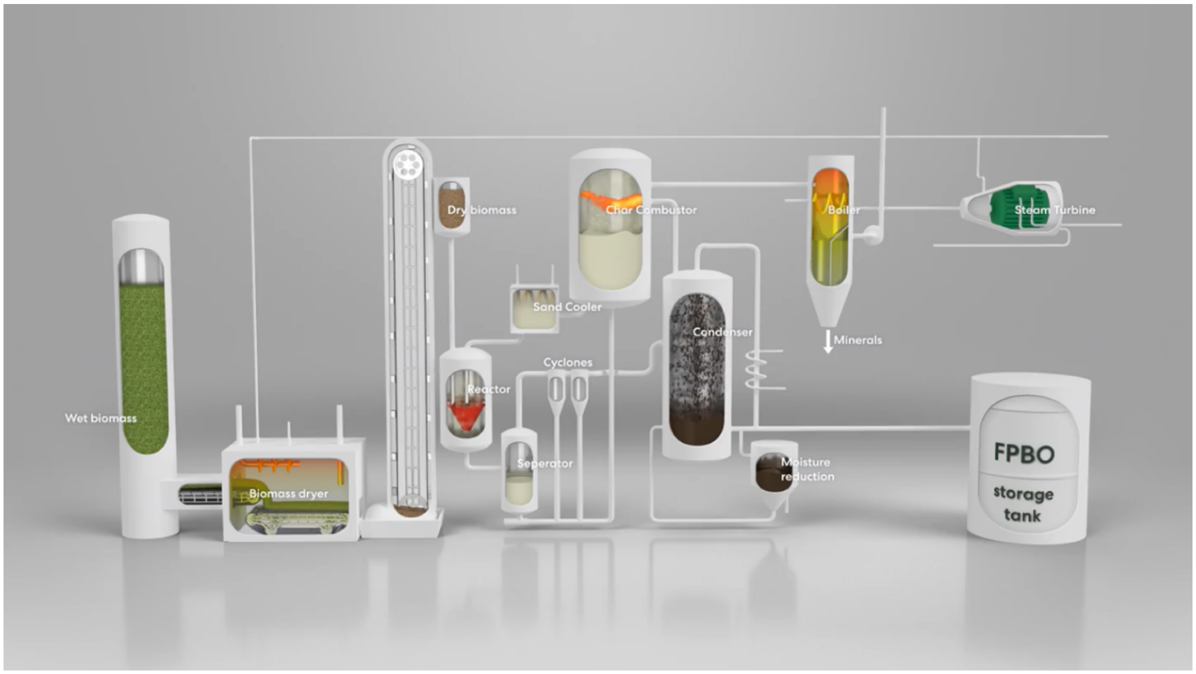


Figure 1. Illustration of the pyrolysis process

During the commissioning phase, BTL is responsible for overseeing the initial plant start-up. They address any early technological or engineering challenges, ensuring the plant is ready for production before it is handed over to their client. While the client is present during the commissioning process, they will only be significantly involved with the plant operation after the handover. Post-handover, BTL provides ongoing support for a specified duration as agreed on in the service agreement with their client. This is done to help the client acclimate to the functioning and operation of the plant.

BTL also provides initial training sessions to new plant operators as part of the commissioning process. BTL's main learning goal is to provide operators with the skill and knowledge to operate the plant safely and independently. However, from their experience, the goal has not been reached with the training programme they currently have.

The catalyst for this research project is the critical need to align new operators' training programme with the company's strategic objectives. With the ambitious strategic goal of selling one plant per month, the company recognised the importance of optimising its existing training programme to reach its learning goal more efficiently. Ultimately, they aim to create a training programme that prepares operators for the initial stages of post-handover plant operation. This would lead to a more efficient installation process for future plants and expedite the withdrawal of the company's intensive support. In this research project, the focus would be on designing and recommending possible improvements for the new pyrolysis plant operators' training programme, so that it aligns with the needs and preferences of all stakeholder groups.

Figure 2. Picture of a commissioned pyrolysis plant

1.3 Relevant Stakeholders

1.3.1 BTL

BTL serves as the service provider. For this project, it is essential to consider their business model, existing resources, ideal business goals, and strategic focus, as it will shape the outlook of new operators' training in the near and distant future. Throughout the project, BTL's needs, experiences, and aspirations were considered as guidelines for creating design recommendations that align well with the company's climate.

1.3.2 The Trainers

Historically, six BTL employees have managed new operators' training. During each commissioning period, an average of three individuals assumes the role of main trainers. The remaining team members are on standby as additional trainers if required. All training team members hold higher education degrees in various engineering streams and possess intimate knowledge of the technology associated with pyrolysis plant operation. It should be noted that BTL trainers have no formal teaching background.

1.3.3 Client Management

While the character of the client management would change with every commissioning project, as is the nature of BTL's business model, taking in the preference of prospective clients regarding new operators' education is crucial. Aligning everyone's understanding of the needs and requirements for operator training is essential to ensure effective operators' education.

1.3.4 The Trainees

The trainees comprise of new operators of the pyrolysis plant. Given the company's global footprint, each commissioning project may involve operators with diverse backgrounds and language skills. Many lack formal education in plant operation, whether academic or vocational. However, most have had experience operating other types of plants (e.g., wood logging, papermill, steam) for two to more than five years before joining the pyrolysis plant. Few operators have no prior operational background (e.g., local politician, truck driver, salesman). Their diverse background, knowledge, and skill level are essential considerations when designing recommendations for an effective training programme.

1.4 Research Objective and Research Questions

This project aims to conduct design-based research that provides practical recommendations for improving BTL's new operators' training program. The following research questions were drafted to provide direction for the operator training design project:

RQ1. What are the core problems and existing gaps that have the potential to be improved within the subject's current training programme?

RQ2. What are the design boundaries that may affect the conceptual and implemental decisions?

RQ3. What design recommendations can be suggested to address the stakeholders' needs while considering existing design boundaries?

RQ4. To what extent do the design recommendations prove to be effective when implemented in real learning scenarios, as assessed by key stakeholders' feedback?

2. DESIGN APPROACH

The design process of this research was guided by McKenney and Reeves' (2018) generic model for conducting design research in education (see Figure 3 for a visualisation of the model). This model aligns with the research project's objectives due to its emphasis on integrating theory and practice. It ensures that the research outcomes will not only have theoretical rigour but also have tangible, real-world applications. This framework emphasises the building of close relations with the project's stakeholders, assuring that final design recommendations will fit their needs.

McKenney and Reeves' (2018) model consists of three distinct phases: Analysis and exploration, Design and construction, and Evaluation and reflection. The next sub-segments will further describe the nature of each phase, and also how they will help answer the research questions shown in the previous segment.

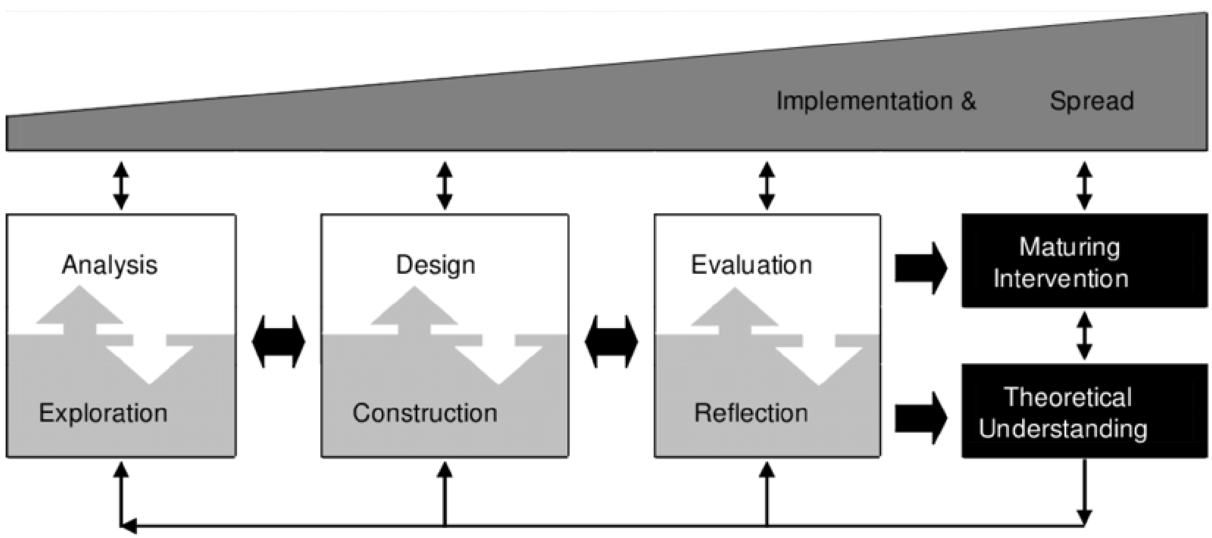


Figure 3. Generic model for conducting educational design research

2.1 Analysis and Exploration

This phase involves a deeper dive into the existing problem through collaboration with key stakeholders. Simultaneously, exploring existing literature provides theoretical insights into the problem and its context. The objective of this stage is to better understand the project's focus, identify stakeholder goals, identify design boundary conditions, recognise problem areas, and identify initial suggestions for potential solutions. The insights gathered in this phase serve as a foundation for the subsequent design phases of the research process.

To achieve said objective, the analysis section of this research project included an initial document review of the existing materials and methods used in previous new operator training programmes, qualitative data collection of stakeholders' opinions and needs, field observation of how BTL and its clients conduct business as usual, and a team strategic meeting for past BTL training team members. Exploration through literature study was also done to support analysis findings. With the proposed activities, the resulting analysis will help answer RQ 1 "What are the core problems and existing gaps that have the potential to be improved within the subject's current training programme?", and RQ 2 "What are the design boundaries that may affect the conceptual and implemental decisions?"

2.2 Design and Construction

This phase covers the development of solutions through collaboration with project stakeholders, as guided by insights from the analysis and exploration stage. Iteration of design is a central element, with prototypes evolving based on stakeholders' feedback to ensure alignment with design boundaries and practical applicability. The outcome is a concrete product or intervention ready for practical implementation and testing. The process of coming up with the design recommendations is guided by scientific literature to ensure integrity and accountability, guaranteeing that the chosen design frameworks and learning principles align with the academic and industry's best practices.

Specifically for this thesis project, this phase involved an initial review of various instructional design models and principles. Subsequently, concrete solutions in the form of a training framework, recommendations of training content, recommendations of learning methods and tools, and trainers' guidelines were developed in collaboration with BTL team members to ensure compatibility with the company's needs. The activities done in this phase will help answer RQ 3 "What design recommendations can be suggested to address the stakeholders' needs while considering existing design boundaries?"

2.3 Evaluation and Reflection

As defined by McKenney and Reeves (2018), this phase involves empirical testing of proposed improvements in collaboration with the project's key stakeholders. This will help assess the suggested intervention for its effectiveness, viability, and impact. The response of the design recommendations' target base played a critical role in determining the intervention's success. In the reflection sub-phase, the overall creation process of the research report and the results of the evaluation session are meditated using the subjective feedback from key stakeholders. The outcomes of this phase are used to refine the designed intervention, inform future iterations, and conclude the design project.

For this thesis project, a smaller-scale training module was developed with the BTL team and served as the pilot implementation for the redesigned training program. The data collected from these sessions were examined and reflected upon to gain a deeper understanding of the strengths and weaknesses of the proposed interventions. Based on this analysis, areas for improvement and future steps were identified. This section also featured a reflection on the report's creation process and the relevance of design recommendations on real-life teaching activities. This was done to gain insight into the positives and the negatives of the journey and reception of the end product, which could then be used to improve the design process of similar projects in the future. The proposed activities will help answer RQ 4 "To what extent do the design recommendations prove to be effective when implemented in real learning scenarios, as assessed by key stakeholders' feedback?"

3. ANALYSIS AND EXPLORATION

3.1 Data Collection

A comprehensive analysis of stakeholders' needs was required to gain a deeper understanding of the current iteration of the new operators' training program. To achieve this, various data collection methods were employed, as elaborated in the following section.

3.1.1 The Trainers

To gain initial insight from BTL's training team, individual, semi-structured interviews were conducted with all BTL employees with experience as trainers in previous new operators' training programmes. Five BTL employees were interviewed over two days, from September 7 to 8, 2023, with the sixth employee interviewed on October 9, 2023. The interviews lasted between forty-five to sixty minutes and were recorded with the consent of the participants for data analysis purposes. The interview was semi-structured, with the researcher being open to exploring all facets of the training team's gripes, triumphs, and lessons learned from their experience in running previous new operators training. General guiding questions were asked on the training team members' role in BTL, their role in past training sessions, the general aim of the operators' training session, general opinion on how the training was done, positive and negative aspects of the training, and how they envision BTL's training programme to look like in the future.

Furthermore, a group strategic activity was conducted with five trainers on October 14, 2023, lasting for three hours. Moderated by the researcher, the session began with a SWOT (Strength, Weakness, Opportunity, and Threat; Stewart et al., 1965) strategy exercise to identify the design boundaries of this project. It was achieved by exploring existing environmental, strategic, or resource conditions that might facilitate or impede the redesign and implementation of the new operators' training programme (McKenney & Reeves, 2018). Next, the group did the Action Priority Matrix activity (see Figure 4; Covey, 1997). Using the matrix, the team mapped change opportunities, as identified from the SWOT activity, on a graph to indicate their impact on the strategic growth of the business and the effort required for implementation. This exercise served as a stakeholder management strategy, as it allowed the BTL training team to come into a unanimous agreement on which aspects of improvements should be prioritised. It also allowed them to be more aware and understand the cost-benefit returns of each potential change. It played an important role in unifying the team's focus on change.

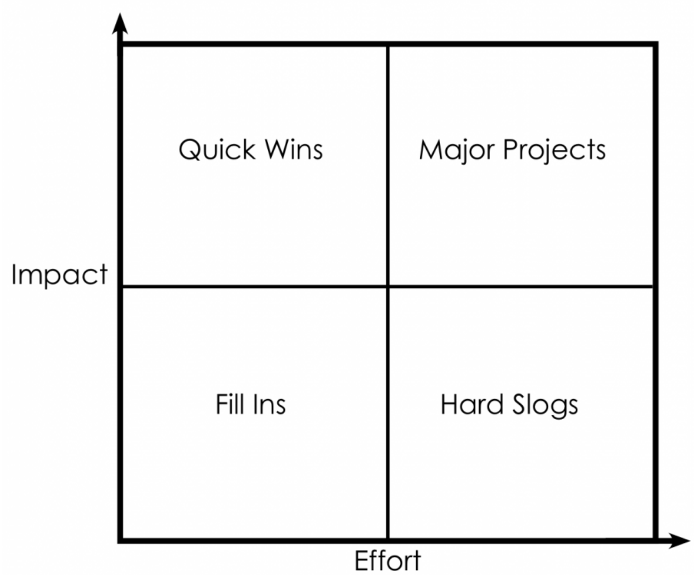


Figure 4. Action Priority Matrix

3.1.2 The Trainees

The method of survey, field observation, small group interviews, and an individual interview were used to gather input from operators who took part in past new operators' training. The survey took place from October 13 to November 3, 2023, with the primary goal of collecting general information on operators' background knowledge, experience, preferred learning methods, and topics they deemed necessary to emphasise during new operators' training programme. The survey was given in a combination of multiple choice and open-ended questions (see Appendix A for the full breakdown of the operators' survey questions). The survey was completed by nine plant operators, selected through a purposive sampling of operators currently and recently employed from two pyrolysis plants. Demographic data were not collected for privacy reasons, due to the small pool of survey participants (Kaiser, 2009). The information gathered from the survey was used to draft the structure for the field observations and follow-up questions for the small group interviews.

Field observations of operators' day-to-day activities were conducted at the Swedish pyrolysis plants over five days, from October 30 to November 3, 2023. No specific coding scheme was developed for the observation, focusing only on observing how operators currently operate the plant in common-practice situations. Clarifying questions to understand their thought process and personal opinions were asked impromptu when moments of note occurred (i.e., after dealing with alarms, before and after daily rounds, and after problem solving group discussions with BTL team members).

The site visits also involved small group semi-structured interviews with five plant operators and an individual interview with the plant's manager. Two interviews, one with two operators and one with plant management, were conducted on November 1, 2023, and a third interview with three operators was conducted on November 3, 2023. The semi-structured interviews, averaging 45 minutes, prompted operators to recall their experience with BTL's new operators' training and discuss how the training impacted their early days of plant operation. For operators who did not participate in the initial training led by BTL, the interview elaborated on the training methods currently employed by the client company. The interviews also explored operators' professional background and how it influenced their learning and work experiences at the pyrolysis plant. Interview participants were chosen through convenience sampling, as only operators and plant management who had their shifts during the site visit were interviewed. Each participant gave verbal consent and was made clear of the nature of the thesis project. They were also reminded that the researcher is an external consultant for BTL and that their response would be anonymised and aggregated in the final report.

3.1.3 Data Processing

The method of inductive coding was used to structure the raw data into comprehensive findings (please refer to Table 3 of Appendix B for a complete overview of the coding scheme). Comprehensive examination and interpretation of data from various points of interest were used to identify the challenges and points of note currently present in the new operators' training programme (Thomas, 2006). Stakeholder responses to individual interviews, group activities, open-question surveys, and small group interviews were compiled, totalling in eleven transcript documents. An initial read of full transcripts of interviews and activities was done to increase familiarity with the material before units of analysis (UoA) were isolated. A total of 161 UoA were identified. Next, initial codes were constructed via an abstraction process. Similar incidents and situational factors were organised into variations, which were then grouped into relevant codes based on information presented in the UoA (Elo & Kyngäs, 2008). From this, three major code categories were identified: contextual information, areas of improvement, and design boundaries, followed by their subsequent variations.

The iterative nature of the coding process meant that there were several changes in the configuration of the codes' variations. Please refer to Table 4 of Appendix B for details on changes between each major iteration. An individual researcher conducted the content analysis and it was not subjected to inter-rater reliability.

3.2 Retrieved Contextual Information

3.2.1 Current-State Training Initiatives

BTL has historically undertaken four pyrolysis plant commissions, with the initial two serving as internal product development projects, and the latter two as external commercial projects. The way the latter two commissions were conducted became the current business model of BTL. This thesis project will focus on analysing the training programs for the two external commercial projects. This means that design recommendations should take into mind BTL's role in the commissioning process, their relationship with clients, operators' demographics, and strategic business goal in order to ensure the applicability of design recommendations for future commercial projects.

The current iteration of the new operators' training programme comprises of a four-day classroom section followed by a period of on-the-job training. The classroom training is normally run after the construction phase is completed (i.e., the plant is physically completed), coinciding with the commissioning/start-up phase. The classroom section is divided into two parts: classroom learning in the morning and practical activities in the afternoon. The morning sessions cover theoretical aspects, including the pyrolysis process, safety procedures, Distribution Control System (DCS), and plant maintenance procedures. During the afternoon sessions, operators will either visit the plant site, where trainers then provide insights into the process flow and process utilities (i.e., process related to how and what materials and by-products go in and out of the plant), or do collaborative work on case studies and simulator training. The classroom section concludes with an assessment to provide proof of training. On-the-job training follows, with operators given control over the plant production while still under the guidance of the BTL team. This training period continues for a duration specified in the service agreement, ending prior to the plant's handover to the client's management.

The overarching goal of BTL's training is to equip new operators with the knowledge and skills necessary for a safe and independent plant operation. The critical question arises: Have BTL's training initiatives successfully achieved their intended outcomes?

3.2.2 Plant Operators' Daily Obligations

Operators currently manage plant operations from a central control room, overseeing plant activities through the DCS displayed on multiple computer screens. They engage in routine tasks at scheduled intervals, ranging from activities that can be completed remotely from within the control room to physical tasks requiring their presence in the plant. For instance, a remote routine involves using the DCS to activate a drill to clean a tube in the pyrolysis oil condenser every three hours. On the other hand, a physical routine requires manually cleaning charred build-up from oil nozzles every six hours. Operators are also entrusted with more complex routine activities, such as the weekly burnout process to eliminate residue from biofuel reactor chambers. Despite being routine, these tasks involve information processing and critical thinking in the form of creating and reading charts to determine when they can stop the burnout. Operators must also be able to handle non-routine alarms and issues, which require them to synthesise plant information, troubleshoot problems, and make informed decisions based on their observations. Additionally, operators must be well-versed in emergency procedures. Amidst these responsibilities, operators also have to maintain effective communication with other operators, the plant manager, maintenance teams, and external stakeholders.

Current observation shows that operators have manifested BTL's learning goal, demonstrating the ability to operate the plant with a degree of safety and independence. They now can identify and address the source of routine problems and alarms, reaching out to BTL only when confronted with new alarms or issues beyond their knowledge and abilities. However, both trainers and operators emphasised that this expertise primarily stems from informal on-the-job, trial-and-error learning. Most operators found that the new operators' training did adequately prepare them for their day-to-day job as plant operators. Consequently, BTL finds itself providing support that exceeds the original time period as specified in the service agreement. Considering BTL's strategic and business goals, prolonged interdependence between operators and BTL team members is suboptimal. This observation exposes existing gaps in the current training program that warrant optimisation. The following sections of the report will delve into a detailed exploration of these identified gaps to gain a better understanding of their context and what recommendations could be given for their improvement.

3.3 Identified Areas of Improvement

This section will go into the state of the current new operators' training programme, highlighting the existing gaps and their observed effects on the performance of current operators. We will explore the potential reasons behind these gaps and possible ideal states, as supported by relevant literature. For a concise summary of the analysis of identified areas of improvement, please refer to Table 1.

3.3.1 Novel information and its implication

BTL is a pioneer in pyrolysis technology, showcasing innovation in its operational processes. However, this technological advancement presents challenges in the education of new operators. The pyrolysis process, relatively unfamiliar outside academic circles focusing on such, and the specialised design of plant equipment and operating system to cater to said process collectively contribute as an obstacle to new operators' learning process. The uniqueness of the pyrolysis plant was significant enough that operators, even with years of experience operating more conventional plants, still needed substantial time to acclimate to BTL's distinctive pyrolysis plant. As one operator said, "Everything is different from what I was used to … I felt like a complete beginner".

Effective learning of new information typically benefits from activating prior knowledge or providing new experiences (Earl, 2010; Hinds et al., 2001). However, document review of training materials indicates that BTL lacks a formal method for activating operators' prior knowledge and recontextualising it to the specific context of the pyrolysis plant. If it occurred, it happened informally through question-and-answer sessions between operators and BTL trainers, potentially resulting in an unstandardised learning experience. On a positive note, BTL's training structure already includes elements such as animated presentations of the pyrolysis process, site visits, and a DCS simulator. These features should help create new experiences on novel pyrolysis topics and contexts that new operators can use as a foundation for new knowledge (Merrill, 2002). However, challenges in understanding the pyrolysis plant's processes persisted, indicating suboptimal utilisation of these opportunities.

If left unchecked, this problem area may lead to difficulties in comprehension, diminished retention, and increased cognitive load in new operators, resulting in a slower learning rate (Mayer & Fiorella, 2021b). This hinders the efficiency and effectiveness of the training programme as learners struggle to create meaningful connections between new and previously existing information (Mayer & Fiorella, 2021b).

3.3.2 Classroom Training Content

The operators and BTL trainers agreed that the current depth of information provided during the classroom training, especially concerning the theory of the pyrolysis process and DCS, was overly technical. It went beyond the knowledge required for operators to conduct daily plant operations. According to one operator, "[the classroom training segment] is like school. You learn [information] that you never use". This hinders the effectiveness of learning, as operators reported feelings of boredom and apathy from disregarding the importance of the training topic, which was shown to be one of the negative emotions affecting learning effectiveness (Pekrun et al., 2017).

The core problem seems to stem from a lack of understanding regarding the specific knowledge operators need to execute their duties successfully. Why give operators in-depth theory when they do not need them? The operators also agreed on this, as they prefer curated learning materials that are highly relevant to their job responsibilities. The BTL training team possesses the necessary information for designing relevant training contents, but they struggle to structure it effectively for new operators. One concrete example of this issue is how new operators struggled with addressing alarms during the initial week of operations. They treated all alarms uniformly due to a lack of guidance on distinguishing their urgency in classroom training. The missing information reduced production efficiency and created a high-stress environment, taxing operators mentally and cognitively. It was a phenomenon that did not need to happen, as BTL has the information to educate operators on alarm severity levels. This difficulty may have stemmed from a mismatch in assumed knowledge between new operators and the BTL training team. The team, composed of highly trained engineers, may have experienced the "curse of expertise," a cognitive bias where individuals with advanced knowledge find it challenging to communicate effectively with those with less expertise (Hinds, 1999). Pushed further by the tight deadline, they felt the need to give too much too soon, and forgot to build from the basics. "We are technicians, we want to explain everything … [the content] is simple to me … I forgot [new operators] are not experienced," one training team member stated. This situation highlights a necessity to better align content creation with learners' needs.

The impact of this problem area appears to be that operators could not construct a robust mental model of the pyrolysis plant. A mental model, serving as a personal and internal representation of the learning subject, plays a crucial role in organising, interpreting, and comprehending new information (Van Merriënboer et al., 2002). This is crucial for complex tasks like operating a pyrolysis plant, as it forms the foundation for operators to apply knowledge to new situations and develop problem-solving skills necessary for their future job obligations (Mayer &

Table 1

Summary of identified areas of improvement, it’s impact on training stakeholders, and proposed key design questions

Problem Area	Main Issues	Impact	Key Design Questions
Novel information and its implication	● Lack of formal method for activating operators' prior knowledge. ● Suboptimal utilisation of training opportunities to understand the pyrolysis plant's processes.	● Difficulty in adapting to the unique plant processes, despite previous experience. ● Informal activation of prior knowledge leads to inconsistent learning experiences. ● Struggles in comprehension and retention hinder learning efficiency. ● Slow learning rate due to challenges in connecting new and existing information.	● How to activate prior knowledge and relate it to the new concept of the pyrolysis plant in a standardised manner? ● How to utilise new experiences as a framework to hang new information on?
Classroom Training Content	● The BTL team struggles to align content with operators' level of expertise, causing missing information and information overload at the same time.	● Reduced learning effectiveness due to perceived irrelevance and cognitive overload ● Operational disruptions due to not having relevant knowledge ● Challenges in schema construction which may cause intuitive beliefs in the long run	● What content knowledge is relevant and necessary to prepare operators for their job obligations? ● How can the training content be better curated and structured to align with the practical demands of the operators' roles, ensuring an effective and relevant learning experience?
Classroom	● Featured assessments	● Operators lack the	● What are the practical skills and performance

Training Assessment & Exercise	are not tailored to practice the skills expected from operators ● Exercises are overly complex	opportunity to practice knowledge application, hindering their ability to address real-life issues effectively. ● Reduced learning effectiveness due to frustration and demotivation from complex exercises	that operators are expected to have at the end of each training segments and its modules? ● What types of assessment and exercise can support the achievement of said skills and performance? ● How to scale assessment and exercise difficulty that follows the displayed level of skills and expertise of operators?
Operators Dependency	● Operators are unprepared to transition from classroom to on-the-job training due to insufficient mental model building and essential skills development. ● The support provided during on-the-job training does not follow effective scaffolding principles, leading to a trial-by-fire learning experience for operators.	● Operators develop detrimental help-seeking habits and maintain a high dependence on BTL trainers	● How can support be phased out sustainably to ensure operators are adequately prepared to perform their jobs independently?
Training Methods and Tools	● Ineffective use of online learning and digital tools for learning due to unpreparedness	● Suboptimal learning effectiveness due to decreased motivation and engagement ● Hindering BTL's overall business goal of rapid expansion	● How can support be phased out sustainably to ensure operators are adequately prepared to perform their jobs independently?

Fiorella, 2021b; Van Merriënboer et al., 2002; Van Merriënboer & Sweller, 2005). If left unaddressed, future operators may encounter challenges similar to those faced by current operators. The objective of this design process is to prevent such difficulties proactively.

3.3.3 Classroom Training Assessment & Exercise

Similar to the opinion on training content, interviews with both stakeholders revealed a problem with the relevancy and depth of the training's assessment and exercise. While formative and summative assessments were incorporated into classroom training, the focus is predominantly on testing operators' rote memorisation of complex topics rather than practicing relevant skills (e.g., completing routine procedures, solving nonroutine issues, etc.). This is supported by operator interviews, which revealed that they prefer hands-on and practical learning exercises. As one operator said, "the [recall] questions at the end of training modules is a waste of time … I like it when [BTL training team] explain [real] problems and show me how to solve [them]". It should be noted that BTL's training program included DCS simulation exercises to allow operators to practice problem-solving skills in a true-to-life environment. However, the potential learning benefit of this simulation practice was eclipsed by the scenarios' difficulty level (Vygotsky, 1978).

The ideal outcome of the training program is for new operators to operate the plant independently and safely. They would need ample time to familiarise themselves with the scenarios, tools, and procedures they will encounter in real life (Lim et al., 2008). However, the training program currently does not support skill development effectively due to unsuitable exercise and assessment methods (Bloom, 2012). Additionally, there is no clear expectation of what operators should be able to perform at the end of each training segment. Document review and interviews with the BTL training team revealed a lack of pre-work done to define the learning objectives for each training segment and module. Made worse by the curse of expertise (Hinds, 1999), this may explain the difficulty spike in training exercises. "Scary, complicated situations … engineers, they like that," one BTL training team said on the topic. Van Merriënboer et al. (2006) suggested that novice learners should start with simple tasks to reduce intrinsic load and help activate essential cognitive processes for learning transfer. In BTL's case, the training team hit the gas from the get-go. These elements, consequently, further impeded the learning effectiveness of the training programme due to learners' frustration and demotivation of having to complete exercises that far exceeded their abilities (Fredrickson, 2001; Mills et al., 2013; Rowe & Fitness, 2018; Vygotsky, 1978).

Operators are affected by this issue in that they lack preparation to advance to a more complex learning environment (i.e., on-the-job training). This becomes evident in their current performance, where operators still experience difficulties addressing nonroutine issues and unexpected alarms due to a lack of practice in applying their knowledge in real-life situations. Addressing these core problems is crucial for bridging the gap between theoretical knowledge and practical application, ensuring operators can confidently and independently navigate the complexities of operating the pyrolysis plant.

3.3.4 Operators Dependency

Operators faced difficulties completing the on-the-job training portion of the training programme. On-the-job training followed classroom training, where hands-on learning with experienced BTL team members should ideally occur. However, operators found the experience to be confusing at best and panic-inducing at worst. "It was just noisy, and the alarms were going off … I did not know what to do," one operator recalled their on-the-job training experience. Environmental distractions were found to impede the learning process of novices (Faber et al., 2023; Mayer et al., 2001). The situation was made worse by the insufficient development of mental models and essential skills during classroom training, as discussed in previous segments. Consequently, operators were not prepared to deal with the higher responsibility and complexity level present in the on-the-job training, as they did not fully comprehend how their actions would impact the plant. This often made them feel unsafe in making changes or trying to independently solve problems. As a result, they seek support from BTL trainers, viewing them as sole experts and a safe space.

In addition to throwing operators to the deep end before they were ready (the impact of which was explained in the previous segments), another issue appeared to be the lack of a clear support structure for operators in navigating a more complex learning environment. Vygotsky's concept of the zone of proximal development (ZPD; 1978) explained that effective learning occurs when learners engage in tasks just beyond their current capabilities, that are achievable with the guidance and support of a more knowledgeable individual. The current training program's support structure lacks the three key characteristics of scaffolding support: contingency, faded, and transfer of responsibility (Könings et al., 2019; van de Pol et al., 2010). First, support was not tailored to the learner's current skill level. Second, instead of gradually fading, it often shifted abruptly from full support to none in between tasks. Due to the commissioning deadline, BTL team members were occupied and unable to fully support new operators at all times. Last, there was a lack of transfer of responsibility. The BTL training team members often retained control over issue and alarm troubleshooting due to trust issues regarding the ability of new operators to handle critical plant problems. By doing so, new operators did not have the chance to fully observe and apply real-life skills, betraying the ideal objective of on-the-job training.

This problem area impacts operators through detrimental help-seeking habits that persist even as they gain better understanding of the plant. This perpetuates a high dependence on BTL's guidance when solving non-routine plant issues, as operators have not been empowered with the tools and strategies to take control of their learning and develop their problem-solving skills (Faber et al., 2023). As noted by a BTL training team member, "When [something new] happens, they will contact [BTG Bioliquids]. Why? Because it is easy." This poses a challenge to one of the overarching training goals set by BTL: "…independently operate a pyrolysis plant."

3.3.5 Training Methods and Tools

In terms of methodology, as previously outlined, the training approach at BTL involves a multifaceted process, combining classroom instruction, site visits, and on-the-job training. A past attempt was made to integrate online learning into the operator training programme, motivated by the onset of the COVID-19 pandemic. However, it was met with dissatisfaction from both stakeholders due to a lack of teacher-student interaction and a one-way flow of information. Their biggest concern stemmed from the high level of disengagement among new operators. In terms of tools, As stated in prior segments, BTL also has a simulation of the DCS for the pyrolysis plant. Using it, BTL may simulate real-life scenarios for training purposes. Unfortunately, the scenarios and user interface of the simulator are not a one-to-one comparison to the ones that operators are using in real life.

The core issue regarding training methods seems to stem from unpreparedness in leveraging technology to support learning. Shortcomings in online learning, such as lack of suitable activities and limited interaction, may lead to decreased motivation and suboptimal learning experiences (Konstantinidou & Nisiforou, 2022; Mayer & Fiorella, 2021a). This finding substantiates the experience of operators. In terms of simulator use, it serves as a learning tool with high physical fidelity, as it closely resembles the actual task environment. While this offers the potential for authentic and immersive experiences for new operators (Van Merrienboer & Kirschner, 2017), there is a gap in ensuring that the simulator perfectly mirrors the software used in operators' day-to-day tasks. This is crucial, as mismatched technology can lead to confusion and delay operators' proficiency in using actual equipment and systems (Roussos et al., 1999). Additionally, studies found that giving novices a high-fidelity practice environment (i.e., simulator) may be detrimental to learning as they are more likely to be distracted by irrelevant and seductive details (Faber et al., 2023; Mayer et al., 2001). Stakeholder interviews support this finding, as they found that more meaningful learning happened when the BTL training team uses the low-fidelity method of studying case studies with Piping and Instrumentation Diagrams (P&ID).

Proper curation and leveraging of existing in-house and in-market technologies are crucial. This should assist BTL in their overall business goal of rapid expansion by reducing reliance on offline classroom training for effective learning. Additionally, it will prevent BTL from falling into the trap of forcing a learning design to fit with the available technology, which would only lead to ineffective learning outcomes (Mayer & Fiorella, 2021a; Timotheou et al., 2022).

3.4 Identified Design Boundaries

This section will discuss the identified boundaries present internally and externally from BTL. We will go through topics such as the current technological advancement, human and informational resources, client relations, and other uncontrollable environmental conditions that may affect the design process of this project. The information stated here was collected from the SWOT group strategic activity.

3.4.1 Available Technology

Being at the forefront of pyrolysis technology, the plant undergoes constant changes and advancements, necessitating continuous monitoring and updating of operators' training content to align with its evolving technology. One of the sources of possible changes in the future is BTL's project towards increased automation. This will reduce operator input in future production processes and, consequently, a different focus in future training programmes.

Currently, BTL is in the process of developing technological tools that can be leveraged for operators' learning. For example, they recently made a 3D scan of the plant, which can be used for a remote virtual tour. They also aim to develop the DCS simulator further to reduce the differences with its real-life counterpart and also to turn it into an online platform. This development can then be used to support independent and online learning modules for training new operators. As BTL operates as a small company with a limited team member, they prefer to strategically prioritise online learning initiatives to optimise their resources. Recommendations on the method of the training programme will consider this condition.

It should be noted that the proposed design recommendations will be made based on the currently available resources and methods.

3.4.2 Trainers

BTL acknowledges the gap in pedagogical knowledge among its training team members. However, they compensate for this with genuine dedication in sharing their knowledge and expertise in the field. Noted from internal team observation and operators' opinions, the training team exhibits crucial soft skills (e.g., good communication, leadership, compassion, and enthusiasm), which aided in fostering a strong relationship with operators. With these skills, optimism, and their self-stated desire to always keep learning, BTL's training team members should be able to gain the skills and knowledge needed to independently implement new and improved iterations of the new operators' training programme successfully (Zeng et al., 2019).

This would be achieved by closely involving them in the design process, providing ample guidance and support during the pilot implementation process, and adjusting the project deliverables to trainers' needs.

To note, despite their commitment in providing exceptional training for operators, it is crucial to acknowledge that training is not BTL's core business. Consequently, during the commissioning process, the preparation and execution of training programs might not be prioritised. It is hoped that this design project's deliverables will help with scheduling and task distribution through clear description of role responsibilities and organisation of resources and time. This, in turn, should reduce potential conflicts during the commissioning process (Dawe, 2003).

3.4.3 Past Experiences & Documentation

The BTL team's extensive experience in commissioning and calibrating two commercial plants is crucial for future operator training programmes. All the necessary information required to construct the training content already exists due to it. Documents such as procedural information, operating manuals, cause and effect explanations, and alarm logs from previous plants will become the foundation for designing the new training program (Van Merriënboer et al., 2006). The challenge lies in distilling this information into a format that enhances the learning experience for operators entering a pyrolysis plant environment for the first time.

3.4.4 Operators' Background

The diversity of operators' backgrounds in knowledge, skill, and expertise is a notable consideration in designing recommendations for the training programme. Moreover, the international nature of BTL's commissioning requires them to be mindful of operators' language abilities. Instances have been observed where operators, struggling during training sessions conducted in English, excelled in their job tasks when provided training materials in their native language. This underscores the significance of addressing language barriers to facilitate effective learning. To address this, there may be a need for BTL to go above and beyond by translating training materials before the commencement of training. This proactive step can enhance comprehension and engagement, ensuring effective learning in operators regardless of their language background (Turki et al., 2020).

3.4.5 Relations Between BTL and Its Clients

With the lack of a standardised training programme, currently BTL has no leverage in setting a schedule and configuration of operator's education to its clients, oftentimes following the client's schedule and preference. It is hoped that by providing a strong concept and evidence-backed training programme, BTL should be able to take a more proactive lead on arranging operator's education (Dawe, 2003). For example, by incorporating it into BTL's standard project planning.

3.5 Initial Design Prepositions

This research project aims to do a holistic review of BTL's existing training programme before providing design recommendations to better align it with BTL's strategic goals and the learning needs of operators. A comprehensive analysis of current training structures, available resources, and stakeholders' insight revealed possible recommendations for improvements:

- Novel information about the pyrolysis plant should be properly introduced to expedite the creation of cognitive schema. This can be done through prior knowledge activation and meaningful leveraging of new experiences.
- Curation of relevant content knowledge and structuring it in a way that aligns with the practical demands of the operators' roles.
- Curation of relevant skills and performance indicators so that training assessments can be appropriately aligned with operators' job obligations.
- Provide appropriate support scaled to operators' expertise and job readiness.
- Suggest learning methods and tools that best support operators' learning preferences and BTL's strategic aspiration.

Based on these analysis findings and close discussion with the BTL management team, several initial design prepositions emerged:

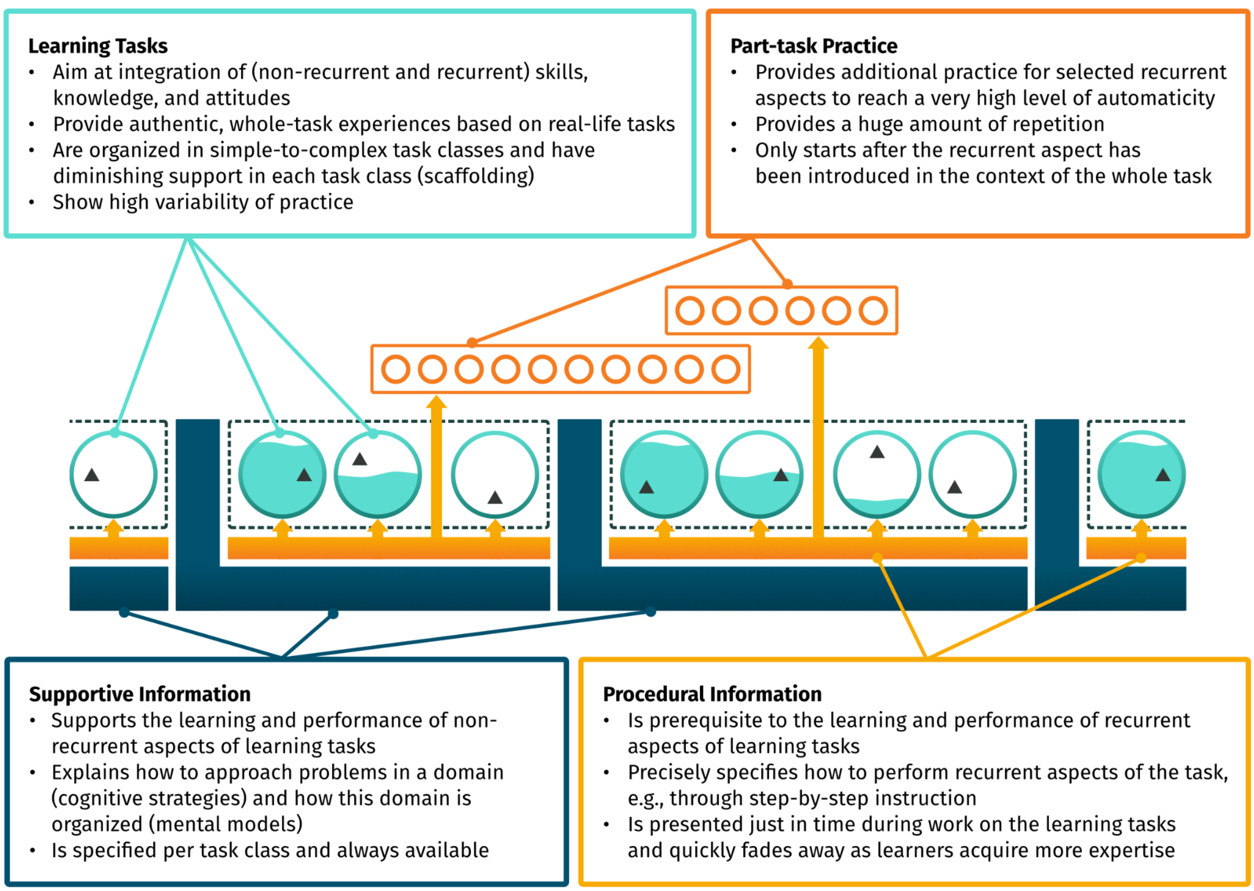
- The creation of an exhaustive training framework to guide the BTL training team in designing and implementing future training programme.
- The creation of trainers' guidelines to help guide the BTL trainer team to use the training framework independently.
- Identify areas within the training framework that can be modified into online learning and recommend suitable design principles to ensure efficacy.

This project will continue to build upon these initial design prepositions in the design and construction phase.

4. DESIGN AND CONSTRUCTION

4.1 4C/ID Model

Operators are expected to independently apply relevant pyrolysis knowledge and plant operation skills in real-life scenarios by the end of the short training period. They are also expected to handle routine activities and utilise critical thinking and problem-solving skills to address novel issues. Considering these learning needs, the 4C/ID model by Jeroen Van Merriënboer (1997) emerged as a suitable instructional framework. The 4C/ID model has demonstrated its effectiveness in being a learning model for various complex fields, such as health education (Vandewaetere et al., 2014; Yardley et al., 2013), teacher education (Frèrejean et al., 2021), and operator vocational training (Mulders, 2022). This track record gives confidence in the suitability of the 4C/ID model as the foundational framework for redesigning BTL's new operators' training program. While several other instructional models were considered, such as experiential learning by David Kolb (1983) and constructivist learning environments by David Jonassen (1997), the 4C/ID model was ultimately selected for its task-centred and holistic approach. Figure 5 displays a visual representation of the model and a summary of its four components.



Note. Adopted from Four-Component Instructional Design by J. G. Van Merriënboer, 2022 (https://www.4cid.org/materials/media/). CC-BY-SA 4.0

Figure 5. *A graphical view on the 4C/ID model*

4.1.1 Learning Tasks (LTs)

The first component of the 4C/ID model is dedicated to breaking down intricate skills and knowledge into authentic LTs. These tasks are designed to mirror real-world situations and challenges commonly encountered in learners' professional environments. This approach encourages the development of practical and applicable skills by leveraging authentic, meaningful, and integrated learning experiences. The 4C/ID model illustration (see Figure 5) depicts LTs as circles. The dotted rectangles that encompass sets of LT circles represent task classes. Task classes group LTs of similar nature together. They progressively increase in complexity throughout the learning process to ensure sustainable scaling of task challenges. Within each task class, learners experience a gradual decrease in support as they acquire more expertise, indicated by the filling level of the circles (see Figure 5). This reduction in support ensures that learners develop independence in completing tasks by the end of the learning period. Additionally, it is crucial for LTs within the same class to exhibit variability, as this facilitates the transfer of learning. This is illustrated by the different locations of triangles within the circles in Figure 5.

4.1.2 Supportive Information

The second component provides the necessary knowledge and information learners need to complete the LTs. They are used to learn and perform nonrecurrent LTs that need problem-solving, reasoning, critical thinking, and decision-making aspects (i.e., nonrecurrent tasks). This includes essential background information, strategic flowchart, examples, expert demonstrations, and other resources that help learners understand how a task domain is organised, and how to approach problems in that domain. By offering context and guidance relevant to the task at hand, learners can better understand the significance of the tasks and build a comprehensive knowledge base of the domain. Supportive information is illustrated as the L-shape underneath the task classes in Figure 5. To note, supportive information is not linked to individual LTs within the same task class but to task classes as a whole. This is because all LTs featured in a task class should draw upon the same body of general knowledge.

4.1.3 Procedural Information

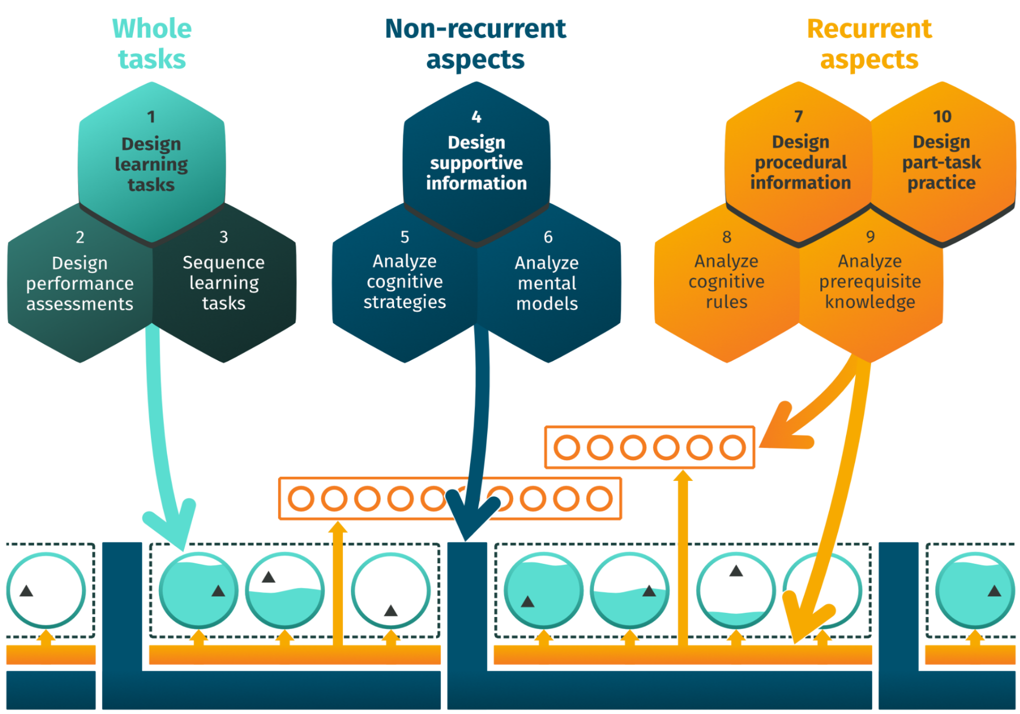
The third component delves into the step-by-step instructions or strategies for executing the LTs. It includes procedural guidelines, instructions, and techniques given just in time as they're needed. This aspect of the instructional model is crucial to ensure that learners gain practical knowledge and skills about the specific procedures and processes involved in the LTs. Another way to give procedural information is through specific feedback before, during, or after task completion. Procedural information is illustrated as arrows in Figure 5.

4.1.4 Part-Task Practice

The final component involves practice items to help learners reach a very high level of automaticity for selected routine aspects of a task. Learners engage in focused, repetitive practice exercises, allowing them to achieve mastery of critical parts of the whole skill that need execution in a near-automatic fashion. Doing this increases the effectiveness and safety of executing the whole task. This incremental approach enhances skill development and promotes a deeper understanding of the subject. Note that you should only conduct part-task practice after its introduction in the context of the whole task. In Figure 5, part-task practice is shown as groups of small series of circles.

4.2 Design Process - 4C/ID Model

The design process for the training recommendations was done following the ten steps of 4C/ID (see Figure 6 for the illustration of how the 4C/ID model is divided into its ten steps). It should be noted that not all steps were conducted in this project, based on the identified needs and conditions of the stakeholders. As Van Merriënboer and Kirschner (2017) stated, "You only need to consult the other chapters if these steps are required for your specific project" (p. xiii). The following section will describe how the 4C/ID model was used to design the recommendations for the next iteration of the new operators' training programme.



Note. Adopted from Four-Component Instructional Design by J. G. Van Merriënboer, 2022 (https://www.4cid.org/materials/media/). *CC-BY-SA 4.0*

Figure 6. A schematic overview of the ten activities in the design process for complex learning

4.2.1 Step 1. Design LTs

During this step, the researcher collaborated closely with the BTL training team to comprehensively understand operators' daily responsibilities. Results from field observation and interviews were used to decide what sets of real-life tasks are needed for operators to achieve the learning goal of the training programme. The analysis revealed a diverse range of activities, each requiring varying levels of skill and process knowledge, and it also revealed the *limit* of tasks that operators are expected to learn by the end of the new operators' training programme. Leveraging their insight into the domain, the BTL training team was tasked to catalogue various real-life scenarios that could be transformed into LTs. This comprehensive list will serve as a base for subsequent stages of the design process.

4.2.2 Step 2: Design Performance Assessment

First, the overall learning goal of the new operators' training programme was confirmed (i.e., "to safely and independently operate the plant"). This goal is then used to identify the skill hierarchy.

What skills are necessary for operators to achieve the overall learning goal? Discussions with BTL training team members revealed that the constituent skills include Safety, Plant Operation, and Plant Maintenance (see Figure 7). Subsequently, various sub-skills for each constituent skill were identified. This process also involved categorising skills as recurrent (i.e., requiring consistent execution of the same behaviour), nonrecurrent (i.e., involving complex cognitive problem-solving), or double classified (i.e., starting as routine but occasionally requiring problem-solving). For instance, Safety and Plant Monitoring was categorised as recurrent, as they are routine and can be mastered through the use of procedural steps and guidance from experienced personnel. Plant Operation was deemed as double classified, necessitating the ability to switch between following procedures and employing critical thinking skills. At this stage, identified LTs were roughly grouped into the skills required for operators to complete them effectively.

Once the skill hierarchy was established, the next step involved determining the type of knowledge required to execute these skills effectively. Given the inexperience of new operators, it was decided that all skills would require supportive information. This means including mental model components, such as process knowledge and hardware information, along with cognitive strategies for addressing alarms and issues. Procedural documents, on the other hand, would be provided only for recurrent and double-classified skills and subskills.

Subsequently, the researcher collaborated with the BTL training team to outline preliminary attitudes and performance objectives expected from new operators post-training (refer to Appendix C for the breakdown of expected ideal performance). This guideline provided direction for the BTL training team in defining the programme's desired outcomes. However, a comprehensive set of attitude and performance objectives was not developed for this project, as it was deemed to be outside of the scope of this thesis project.

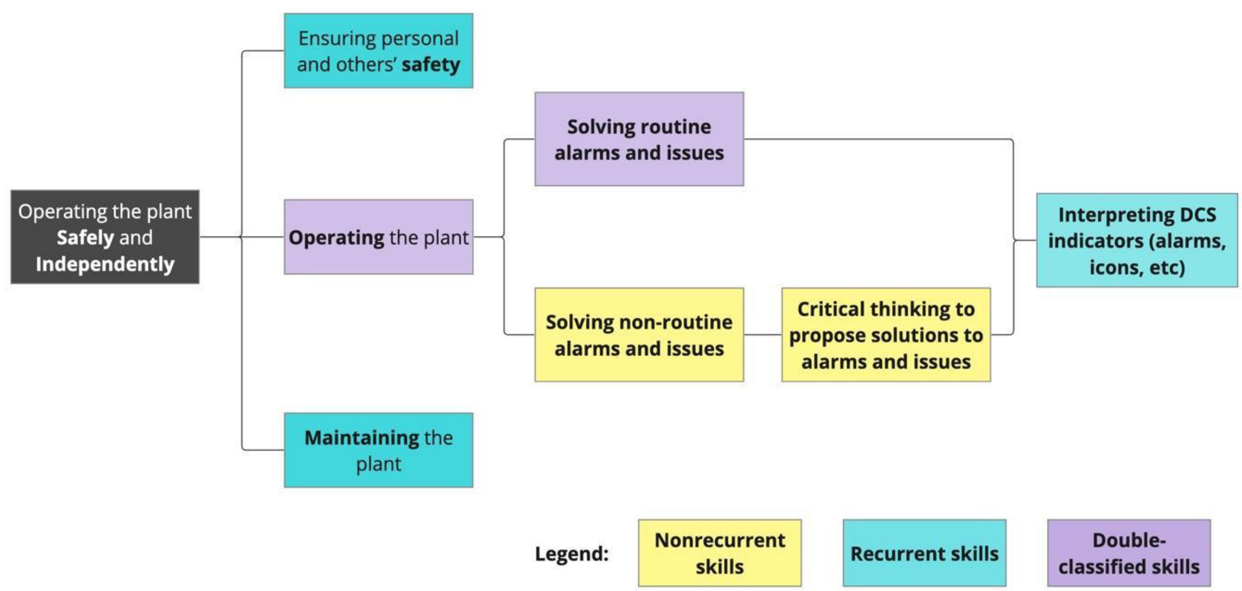


Figure 7. Skill hierarchy of pyrolysis plant operator

4.2.3 Step 3: Sequence LTs

The configuration of the task classes went through several iterations. Initially, it was proposed that each task class corresponds to distinct areas of the plant, with the LTs representing all the tasks that may present in that area. However, after further study of the skill hierarchy and having discussions with BTL training team members and a 4C/ID subject matter expert (SME), it was decided that task classes would instead represent the varying complexity of operators' job obligations. This approach was done to prevent the compartmentalisation of knowledge of the plant's processes. By integrating LTs from different areas of the plant within one task class, operators would be encouraged to develop a comprehensive understanding of the plant's processes, spatial information, and cause-and-effect relationships between modules and areas (Van Merriënboer & Kirschner, 2017). This approach also mirrors real-life scenarios where operators must address problems as they arise, which would occur at random. This requires them to be able to quickly assess how the issues relate to the plant's processes as a whole. The final configuration of task classes is as follow:

1. Routine simple DCS actions
2. Routine simple combination actions (DCS and physical)
3. Dealing with simple alarms and DCS indicators
4. Routine complex combination actions (DCS and physical)
5. Dealing with safety (hazards, LOTOTO [lock out, tag out, try out procedure], emergency procedures)
6. Dealing with intermediate alarms and DCS indicators
7. Dealing with abnormal/nonroutine alarms and DCS indicators

The task classes go from simple to complex. The simplest task class, in this case, means operators are faced with LTs where they have to solve routine alarms/issues from the comfort of the operating room. Increasing complexity comes in a change of physical environment (i.e., operators will eventually have to go to the plant to complete certain routine actions), presence of hazards (i.e., operators will eventually be shown how to procedurally deal with the plant when there are hazards or emergencies), breadth of issues (i.e., operators start from solving issues isolated in one area, and grow into solving issues that include several areas, demanding them to have a better grasp of inter-relationships of the plants' modules), and the nature of recurrence of alarms/issues (i.e., operators will eventually have to solve double-classified issues and non-routine alarms never seen before).

During the discussion, it was agreed that most real-life whole tasks for routine physical actions and plant maintenance would not be included in the classroom training but instead incorporated into the on-the-job training segment of the programme. This decision was made because these tasks are physical, routine, and strictly procedural. Operators would benefit most from learning these tasks by observing demonstrations just before performing them (Fryling et al., 2011).

4.2.4 Step 4: Design Supportive Information

The identified task classes guided the discussion on what domain-specific information and cognitive strategies are required for each class. It should be noted that in-depth identification of domain model information and cognitive strategies for each task class was not done for this project as it was agreed to be outside of the scope. Only broad suggestions were given.

4.2.5 Step 5 & 6: Analyse Cognitive Strategies & Mental Models

This step was omitted in this thesis project. BTL has all the necessary information on supportive information documented in various formats (e.g., operating manual, SOP, logbook, etc).

4.2.6 Step 7: Design Procedural Information

From the identified task classes, guidelines were developed outlining the cognitive rules and prerequisite knowledge necessary for each task class. However, it is important to note that this project did not delve into in-depth content identification and design for these cognitive rules and prerequisite knowledge due to scope limitations. Instead, only broad suggestions were provided.

4.2.7 Step 8 & 9: Analyse Cognitive Rules and Prerequisite Knowledge

This step was omitted in this thesis project. BTL has all the necessary information on procedural information documented in various formats (e.g., operating manual, SOP, logbook, etc).

4.2.8 Step 10: Design Part-Task Practice

This step was omitted in this thesis project. Field observations of actual operators' responsibilities and discussions with the BTL training team revealed that mastering constituent skills does not require operators to train any part of the whole task to the point of automation.

4.3 Product Description and Justification

From the exploration of 4C/ID ten steps with the BTL training team members, several deliverables were produced:

1. Design guideline for online pre-training package
2. Design guideline for classroom training
3. On-the-job training checklist template
4. Trainers' guideline

The first three guidelines focus on developing a structured framework on how the recommended new operators' training programme should run. They go into detail about the suggested sequence of topics, background information, and method of learning as guided by the 4C/ID framework. The fourth deliverable serve to fulfil BTL's goal of independently designing and implementing effective operators training in the future. The full copy of each deliverable can be found in their respective appendices. The following sections serve to give general description and design justification of each deliverable.

Note that these deliverables serve as proof of concept to show the BTL training team how the re-designed new operators' training programme will be structured. The content and breakdown within each deliverable are subject to change once the BTL training team implements the recommended design.

4.3.1 Design Guideline for Online Pre-Training Package

Discussions with BTL training team members revealed the desire to provide new operators with a general, high-level introduction to the plant, its processes, and the DCS before the classroom training begins. To align with BTL's aim of offering more online learning opportunities, it was decided that this high-level theoretical and supportive information would be delivered to operators through an online platform, hence its name, the online pre-training package. The deliverable document outlines the configuration of the suggested additional training segment (see Appendix D for the complete document). It covers the aim of the online pre-training itself, structure and content suggestions for the welcome page of the online environment, topic and activity breakdown of each learning module, and recommendations on self-reflection prompts to increase engagement and self-regulation in new operators.

Several reasons supported the decision to include this additional segment in the new operators' training. Firstly, the package will help provide a theoretical foundation that supports the development of robust mental models related to the operation of a pyrolysis plant. It should prepare operators for the more intensive classroom sessions by activating learners' prior knowledge and providing them with relevant new experiences (Merrill, 2002; Van Merriënboer & Kirschner, 2017). Additionally, by offering a clear introduction to the organisation of the plant domain, the pre-training package helps prevent operators from forming misconceptions about plant operations in the future (Van Merriënboer & Kirschner, 2017). This package also aimed to optimise time usage. By transferring the high-level theoretical base knowledge on pyrolysis, DCS, and safety to a self-directed learning programme, BTL can concentrate the classroom training on applied exercises of LTs to develop key skills in new operators. Furthermore, the decision to deliver the pre-training online aligns with the principles of adult learning theory, offering flexibility and autonomy for learners to engage with the material at their own pace and convenience (Edmonds & Pusch, 2022; Lu et al., 2022). This should fit with the demographic of the training, which comprises adult learners. Lastly, by incorporating multimedia elements and encouraging active participation through self-reflection prompts, the pre-training should engage learners more effectively, promoting deeper understanding and retention of the material (Lu et al., 2022).

Since operators will not be encountering LTs during this phase, the focus will be on organising the plant domain through conceptual, structural, and causal models. This is done to ensure content relevance by not providing information that is not immediately applicable (Van Merriënboer & Kirschner, 2017). However, a safety module is included to address regulatory requirements. Visual demonstrations and real-life examples are integrated to maintain the significance of the information (Van Merriënboer & Kirschner, 2017).

In terms of the deliverable itself, the document will provide a structured approach to help the BTL training team create a learning environment that is simple yet engaging. This ensures that operators gain awareness, understanding, and retention of key concepts to effectively prime them for successful participation in the next steps of their training programme (Van Merriënboer & Kirschner, 2017).

4.3.2 Design Guideline for Classroom Training

Discussions with the BTL training team confirmed that the classroom training would incorporate all identified task classes from the "Sequence LT" activity outlined in the 4C/ID ten steps (see Appendix E for the complete guideline document). As mentioned earlier, the task class grouping was determined based on the daily task obligations realistically expected of operators. It is structured so that by the conclusion of the classroom training, operators would possess the knowledge and skills necessary to handle the more intensive hands-on learning requirements in the on-the-job training phase. The level of complexity and LTs featured within each task class was decided based on the skills and knowledge deemed essential by the BTL training team for the initial six months to one year of new operators. Further re-training on more in-depth skills would be provided based on operators' needs.

The design recommendations for classroom training addresses several key issues identified in the current training programme. First, is the creation of task classes, referred to as "Training Modules" in the deliverable document. As stated, these modules were curated via the 4C/ID's second step: sequencing LTs. Through this, the recommendation focuses on whole-task learning, ensuring that the tasks assigned to operators are relevant, appropriately scaled, and scaffolded according to their expected skill and knowledge levels (Van Merriënboer & Kirschner, 2017). This emphasis is reflected in each classroom training module, which features LTs inspired by real-life issues and alarms. Additionally, by featuring realistic difficulty scaling in the structure of the training modules, the suggested classroom training structure should prepare operators to gradually gain the expertise and confidence to tackle complex, real-life scenarios (Tomlinson et al., 2003; Van Merriënboer & Kirschner, 2017).

In the content breakdown of the eleven modules, the guideline's high-level dissection of required supportive and procedural information for each identified task class ensures that operators receive information tailored to solve the featured LTs. This addresses the issue of irrelevant information overload in the current training programme (Van Merriënboer & Kirschner, 2017). Furthermore, the guideline addresses the problem of unsuitable use of learning methods and tools through its breakdown of activities and related materials. Recommendations for the modes of exercises and their fidelity levels ensure the appropriate use of tools and media to enhance cognition and facilitate understanding of complex tasks (Van Merriënboer & Kirschner, 2017).

This guideline is a robust repository of task classes and LTs for the BTL training team. It serves as a skeletal framework to be filled with actual training content during the design implementation of the recommended framework.

4.3.3 On-the-job Training Checklist Template

The use of observational learning by providing a precise demonstration of expected performance for new operators to observe and emulate is a great way to learn physical skills (Bandura, 1969). Thus, a decision was made to put mostly physical, repeatable, and quickly learned activities to the on-the-job training. This was done so that new operators can quickly apply their skills in relevant settings, where they're immediately beneficial (Bandura, 1969; Fryling et al., 2011).

This deliverable is a checklist of mostly routine physical and maintenance activities that operators need to master by the end of the on-the-job training period (see Table 6 under Appendix F for the template). There are two checklist columns for each skill, one to note initial expert demonstration, and the second is to note that operator have shown ideal performance. The space for feedback beside each skill breakdown is reserved for BTL training team members to write down areas of improvement. This is done if, during the performance assessment, new operators still display serious errors, which indicates that they need further guidance. This template represents a strategic design choice aimed at monitoring the learning progress of new operators. It should also facilitate the process of providing ongoing assessment and feedback based on operators' performance, a form of procedural information crucial to the 4C/ID model (Van Merriënboer & Kirschner, 2017). This approach offers a more sustainable way to structure the support given to new operators, which should help alleviate the current issue of over-dependence on the BTL team (Van Merriënboer & Kirschner, 2017).

This template document serves to help the BTL training team keep track of operators' learning during on-the-job training to keep it structured, even when learning happens outside of the classroom. Through repeated exposure to ideal performance standards, operators should be able to internalise best practices and refine their skills through practice and feedback (Bandura, 1969; Van Merriënboer & Kirschner, 2017).

4.3.4 Trainers' Guideline

BTL training team members recognised the need to develop the skill and knowledge needed to independently design and implement operator training programs, as they have a strategic goal to provide routine re-training for operators in a more structured manner. This deliverable was created to assist the BTL training team in achieving said goal (see Appendix G for the complete copy).

This deliverable condenses the ten steps of the 4C/ID framework (Van Merriënboer & Kirschner, 2017) into an easily digestible document, serving as a "train-the-trainer" guide. Utilising the framework itself for how the document is used, it acts as supportive information for the training team, providing guidance for a better cognitive strategy throughout the phases of a training's design and implementation. This document helps challenge the training team members' preconceived notion on what goes into preparing a training module. For example, by featuring the step of learners' needs analysis, the guideline encourages the BTL training team to align the desired operator skills and the training content. This mitigates the risk of presenting overly difficult material and exercises, which should address the current problem of the training team's "cure of expertise" (Hinds, 1999). Being a supportive document, each phase of the guideline is accompanied with rules of thumb, tips-and-tricks, and suggested troubleshooting strategies. They cover the topic of how to increase cognitive activity, course interactivity, student motivation, and time management, which can be used by the training team when designing a training module.

To extend further on the use of 4C/ID framework in preparing BTL's training team's independence, the guideline is used as a part of their own learning in designing and implementing a training module. It served as a supportive document in the creation of the pilot implementation, itself a practical LT for the BTL training team. It is understood that instilling the skills and knowledge of designing a training with the framework of 4C/ID is a tall order. Not only because of the intricacies of the 4C/ID framework, but also the admitted lack of pedagogical experience of BTL training team members. This is why the researcher was always present to help give constant support for the BTL training team members when using the guideline to design a training module. For example, the researcher would give thoughtful discussion prompts as the team went through the steps in the document (i.e., "Why is it key to decide on learning objectives before going further in creating a training module?" or "Why do you think it's important to make the exercise scenarios go from easy to complex?"). This was done to help strengthen their mental model regarding the steps needed to create a training module.

Overall, the guideline aims to equip the BTL training team with the necessary tools and strategies to design and deliver training programmes with maximised learning outcomes that meet the needs of operators.

5. EVALUATION AND REFLECTION

5.1 Evaluation - Pilot Training

A pilot implementation of the design recommendations was run to evaluate the effectiveness of the recommended 4C/ID model in training operators. Ideally, this pilot would have taken place within the exact environment for which the recommendations were designed, namely the initial training program for new operators. However, since BTL is not currently engaged in any new plant commissioning process, minor adaptations were made for the pilot. Collaborating with the BTL training team and their Swedish client, it was determined that the pilot would focus on re-training established operators in a particular skill that requires improvement.

The design of the pilot training module and implementation of live training sessions served as a trial run for the BTL training team members. While the researcher provided guidance, the BTL training team members used this opportunity to use the trainers' guideline design deliverable document to fill the skeletal design guideline with tangible content. This pilot thus doubles as a "train-the-trainer" opportunity, enabling the team members to conduct future training sessions independently without external guidance (Sartori et al., 2018).

5.2 Participants

Four operators from the Swedish plant, each with at least one year of experience, participated in the pilot training. Only one operator had undergone the new operators' training program, while the other three joined the company afterwards. All operators had intermediate-level English proficiency, sufficient for comprehending the training materials. Additionally, three members of the BTL team attended the training, with two actively delivering the training and one observing.

5.3 Pilot Training Module Creation Methodology

The module creation process followed the instructions outlined in the "Trainers' Guideline" deliverable. Additionally, the pilot training module corresponds to Learning Module 11 in the "Design Guideline for Classroom Training" deliverable. It focuses on LTs that deal with abnormal/nonroutine alarms. While current operators are proficient in monitoring the DCS and resolving routine alarms and activities, they still struggle in solving nonroutine issues that require critical thinking. Therefore, the aim, activity, types of information, learning material, and scenario guideline of Learning Module 11 became the foundation in creating this pilot training. The following section will explore the module creation process in more detail.

5.3.1 Learners Need Analysis

Several potential training topics were collected following a needs analysis via field observation during BTL's last maintenance stop in 2023. Finalisation occurred after a discussion with operators and the plant manager of the Swedish plant, ensuring alignment with operators' needs. They agreed that the training topic would focus on cause-and-effect thinking in dealing with trips and interlocks. For more context, interlocks are a safety mechanism that are set to prevent certain equipment from restarting until specific conditions are met. They are often triggered by trips (i.e., an automatic stop of an equipment or process) in response to abnormal conditions or threats to the system or equipment. To solve interlocks, operators need to know how to gather information on interlock conditions, understand the production process to infer cause-and-effect reasoning, and employ critical thinking to propose solutions. Operators mishandle interlocks by disregarding necessary conditions and immediately attempting to start equipment without considering how it might impact other equipment and the plant's processes. This approach undermines the plant's operational efficiency in the long term.

In the identified skill hierarchy, this corresponds to the sub-skill of "solving non-routine alarms and issues", which demands critical thinking skills and the recurrent skill of interpreting DCS indicators. The training content ensures that the necessary sub-skills to master the main skill are included and practised.

5.3.2 Design Boundaries Analysis

Design boundary analysis was conducted to determine training logistics and external resource requirements. This includes trainer selection, training location, and training duration. This involved scheduling the training session based on operators' availability. Due to time limitations, it was agreed that the training would be done through an online classroom, with three sessions planned to accommodate varying operators' schedules.

5.3.3 LT Analysis, Learning Objective Identification, Task Structuring

LT analysis, learning objective identification, and task structuring were done simultaneously. To do so, first, the researcher asked the BTL team members to provide a real-life example of interlocks that operators struggle with. Then, BTL team members were asked to demonstrate how they would ideally deal with the scenario and identify the areas of their ideal solution in which operators may still struggle to follow. From there, BTL team members were instructed to discuss the skills needed to navigate the scenario drafted up successfully. The outcome of this exercise was a clear list of learning objectives of the training session: (a) Operators can think critically to determine the effect of their decisions when proposing solutions to interlocks; (b) Operators know how to use the interlock flowchart to deal with interlocks; (c) Operators can thoroughly investigate the cause of interlocks by following the step-by-step guideline to navigate the DCS and gather information; (d) Operators can independently apply their new knowledge in other situations. The researcher subsequently guided the training team members in creating a set of ideal performance objectives based on the learning objectives, which served as the foundation for developing the assessment rubric for the pilot training (see Appendix I).

In creating LTs, BTL training team members were reminded to collect real-life scenarios that vary in theme and complexity. In this training, complexity was reflected in the number of modules, areas, and DCS screens involved in issue resolution. Four real-life LTs were identified and divided into two task classes. Task class one included LTs where the interlock was isolated in one plant area and could be solved without moving DCS screens. Task class two featured LTs which required operators to investigate and manipulate surrounding areas to resolve the interlocked module.

The researcher and the BTL training team also discussed support levels for the LTs, agreeing on a range from full (i.e., complete demonstration by team members) to none (i.e., operators solving scenarios independently). Support would gradually decrease in between, transitioning from demonstration to suggestive hints and reminders when operators showed confusion or took inaccurate steps. The final LT (i.e., the one with no support) was used by the BTL training team to assess operators' skill level and understanding of the training topic, using the performance assessment rubric. Additionally, operators' performance on the final LT was taken into context in evaluating the effectiveness of the design recommendation.

5.3.4 Content Analysis

The next step involved content analysis to determine the information and procedures operators need to complete the LTs. The BTL training team revealed their ideal procedure for dealing with interlocks. They were then tasked with documenting these procedural steps in an interlock flowchart (see Figure 8), serving as supportive information to strengthen operators' cognitive strategies. Additional domain information related to process knowledge of interlock scenarios will be given to operators before each LT.

Procedural information was also given as a detailed how-to document on navigating the DCS to gather necessary information when dealing with interlocks. This serves to strengthen the recurrent subskill of "Interpreting DCS Indicators".

5.5.5 Learning Mode Analysis

Following this, discussions were held regarding the learning modes for the pilot training. Given the time constraints, it was decided that the training would be conducted online. Drawing from past experiences, emphasis was placed on collaboration and class discussion. To support this, the researcher provided question prompts to the training team, which can be used to engage operators and promote self-monitoring of their understanding. Discussions were also made on how to practice the LTs, with the team deciding to utilise the DCS simulator. However, not all LTs would be presented using the simulator. Following the guideline of Van Merriënboer and Kirschner (2017), it was decided that operators would practice the first LT with low physical fidelity of the simulator (i.e., screenshots), while LTs two to four would transition into the simulator. This approach aimed to eliminate distracting details that could divert operators' attention, considering the simulator's potentially confusing visual cues, such as blinking lights of false alarms (Alexander, 2019; Mayer & Fiorella, 2021b).

To align with the design recommendation, an online pre-training package (from now on referred to as "homework") was planned for operators to complete before joining the training sessions. The homework followed the general design guideline suggested in the "Design Guideline for Online Pre-Training Package" deliverable. It included an introduction to the training topic, learning objective, procedural document, and the first LT. Following discussions with the training team, it was decided to incorporate four part-task sequences (PTS) into the homework, as the team believed the first LT might still be too complex for the operators. These PTSs covered the information-gathering process necessary to solve the first LT and were presented with screenshots and narrative cases. Operators were tasked to consult the procedural document to solve the PTS. The homework aimed to familiarise operators with the training objectives and procedural information, and refresh their knowledge of interlocks and trips. The homework also doubles to assess operators' understanding and identify misconceptions (Earl, 2007). Operators thus solved the first LT independently, without guidance or supportive information, to allow the training team to gauge their actual approach to interlocks and trips. The training team members subsequently would base their teaching approach on operators' performance in the homework.

5.5.6 Content Creation

With the preparatory work completed, the BTL training team members and the researcher began creating content according to the agreed training format.

Interlock Flowchart. This flowchart (see Figure 8) was developed by BTL experts. It served to guide operators through the steps that need to be taken when diagnosing and resolving interlocks. This served as a supportive information.

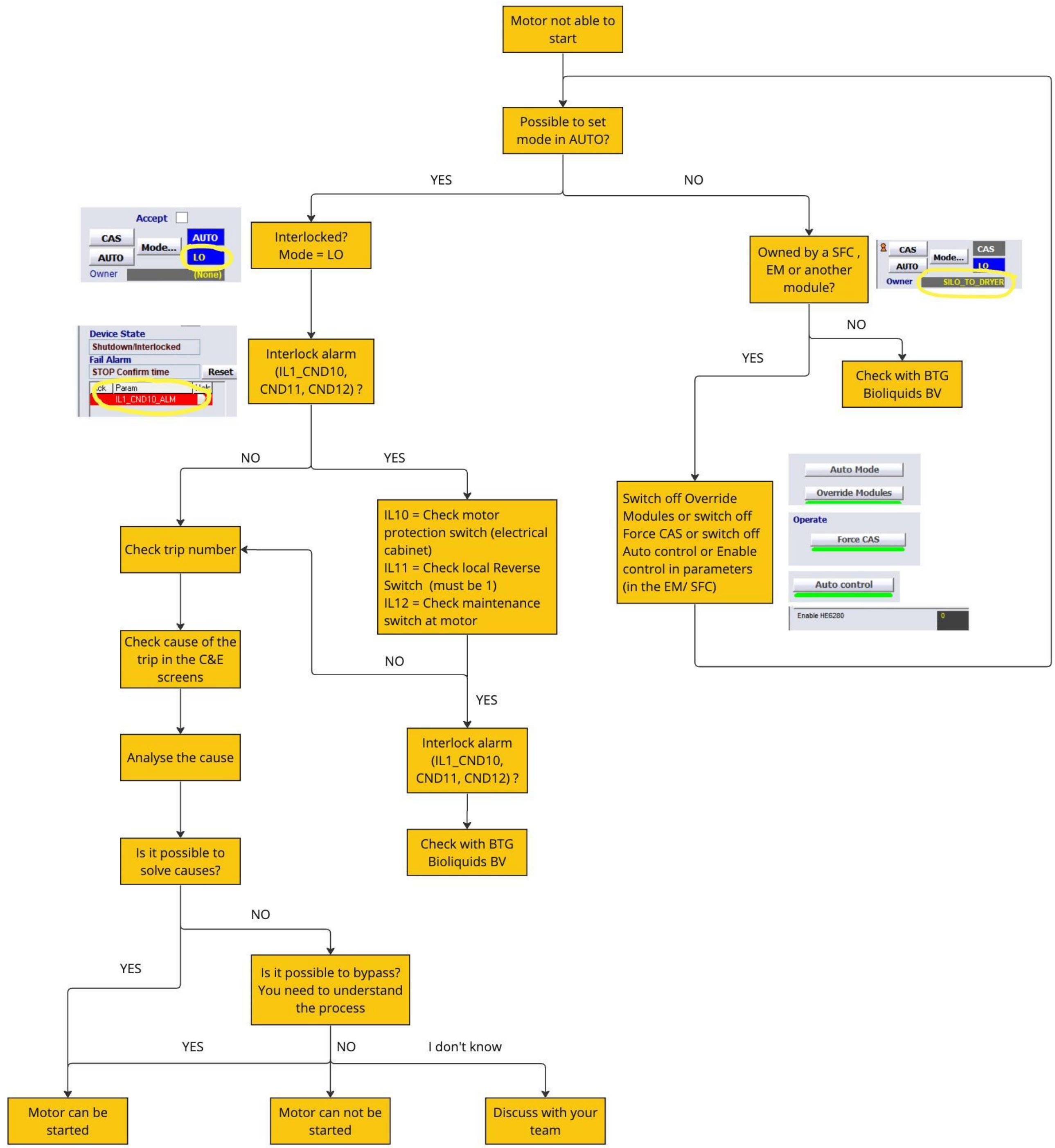
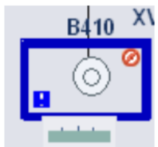


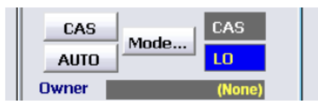
Figure 8. Interlock Flowchart

Interlock Guideline Document. This document introduced the training topic, learning objectives, and key terminologies. It also contained procedural information in the form of detailed how-to instructions to navigate the DCS during interlock. Operators were encouraged to utilise this document when completing the homework and in-class scenarios. See Figure 9 for an example section of the interlock guideline document.

<table>
<tr><th>#</th><th>Explanation and Screenshotted Guidelines – Interlocks in Modules</th></tr>
<tr><td>1</td><td>How to know if you have an interlock at hand?

If a module is interlocked, there will be a icon at the bottom left corner of the graphic on the DCS screen. For example, the screenshot below shows an interlocked B410, which is a part of XV410. This blower can't be started until its interlock is solved.


</td></tr>
<tr><td>2</td><td>Clicking on the icon opens the faceplate of the module (see bottom left screenshot). That the module is interlocked is shown by:

• 
 LO Mode, which stands for LOCKED.

Clicking on the "Detail" icon on the bottom left corner pulls up the detail faceplate (see bottom right screenshot), which shows all the conditions that may interlock the module.

To determine which interlock condition is actively causing the current interlock, the same method as before is used: If the text is bold, the condition is active, if the text is light grey, the condition is not active.

In this example, the following interlock conditions are active:
• T206 or T221 trip
• T405 trip

The red arrow points at "T405 trip". The logic from the previous section applies here: it means that this condition was the first condition that triggered the interlock. You can use this information for your analysis of the root cause of the interlock.

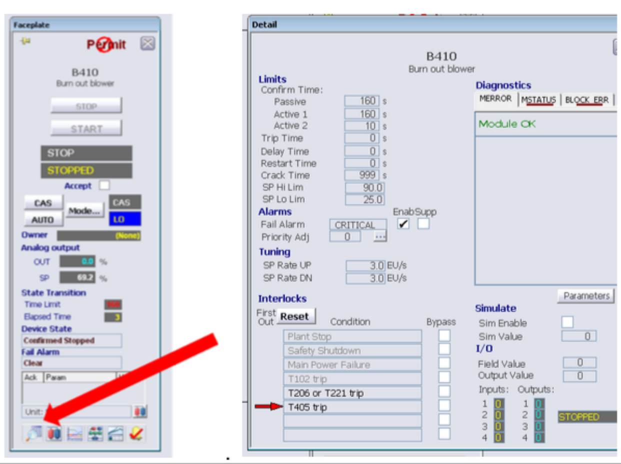

</td></tr>
</table>

Figure 9. A segment of the interlock guideline document focusing on finding interlock in modules

Simulator Program. The BTL training team developed multiple scenario programs in their simulator software. Additionally, they created "exceptional" scenarios for the LTs to provide extra challenges in case operators exhibit a higher baseline knowledge of the training module. See Figure 10 for a visualisation of how the DCS simulator looks.

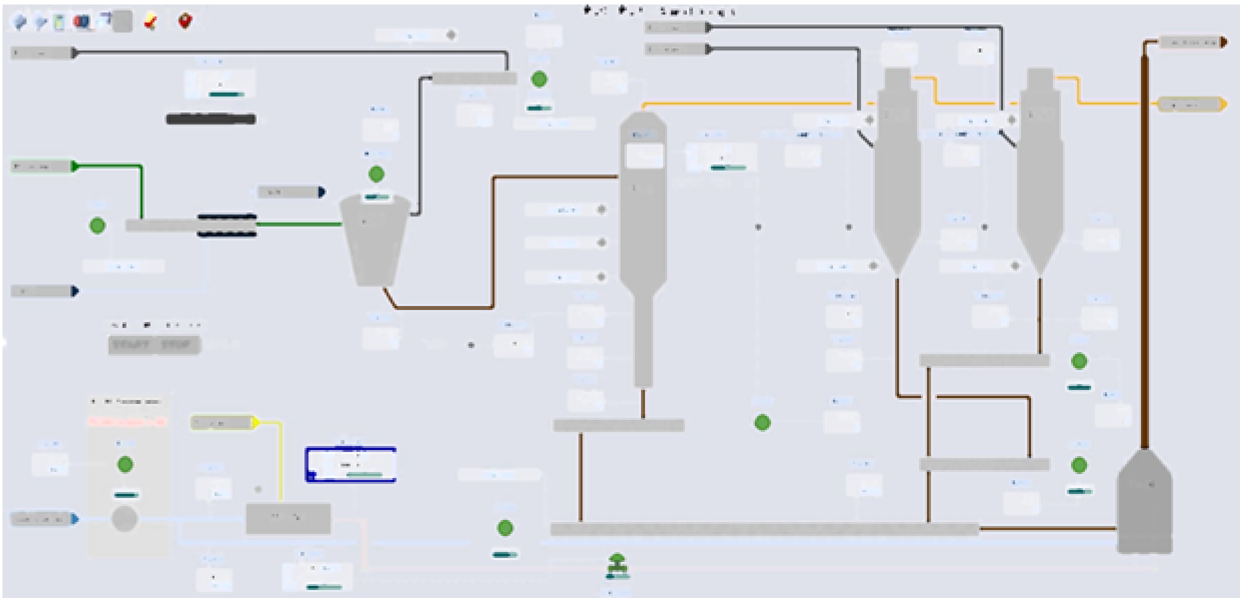


Figure 10. DCS simulator page for the sand loop DCS screen (process values blurred for security reasons)

Homework Environment. The homework was created using Google Forms, consisting of 12 open-ended questions that typically require 30 to 45 minutes to complete. These questions range from completing simple PTSs (e.g., identifying the module owner, listing interlock and trip conditions) to solving entire LTs (e.g., describing the steps to restart a tripped module safely).

Presentation Material. A PowerPoint presentation was developed for the pilot training, featuring an agenda, learning objectives, screenshots demonstrating correct answers for the homework, and an introduction to subsequent LTs. The presentation adhered to the multimedia principle, particularly the signalling principle, using brightly coloured arrows and boxes to guide operators to important information (Fiorella & Mayer, 2021). Additionally, the content was written in clear and concise language to mitigate language barriers and cognitive strain (Yang & Farley, 2019). See Figure 11 for a visualisation of how the presentation material looks.

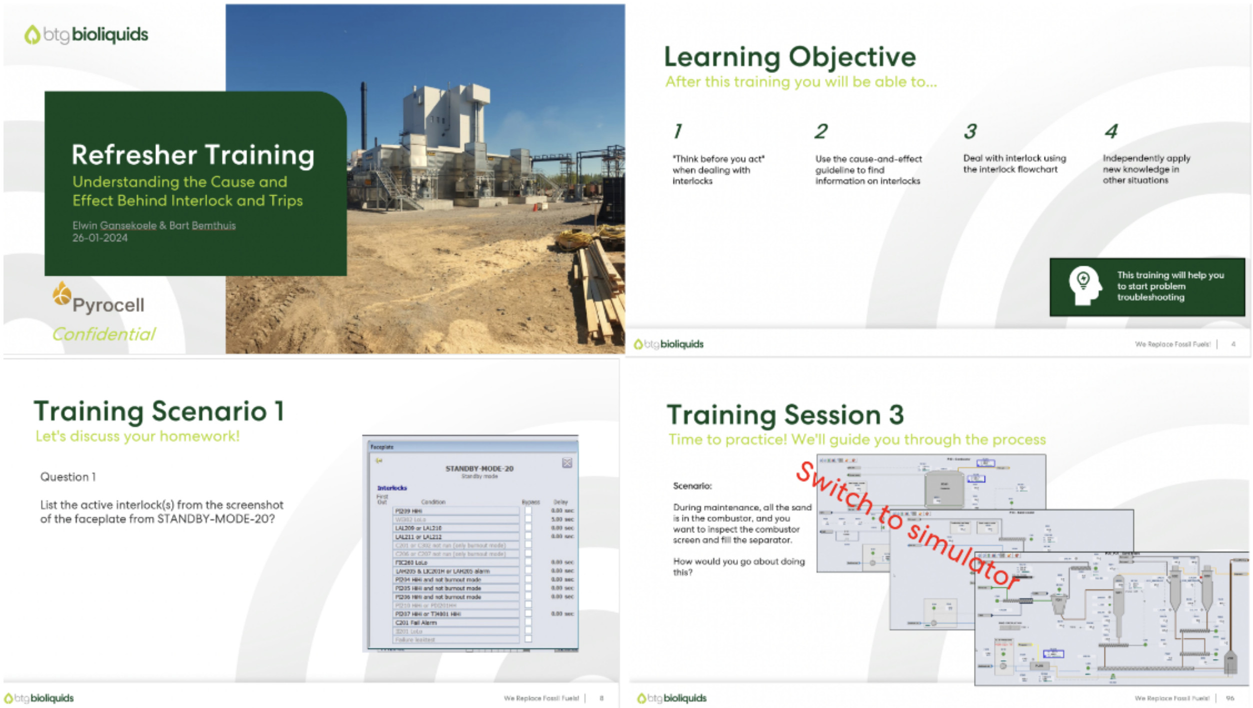


Figure 11. Presentation slides for the interlock pilot training

Pilot Trainers' Guideline. (See Appendix H for a full copy of the pilot trainers' guideline). This document provided supportive guidance for BTL training team members when conducting the pilot training sessions. It included clear breakdowns of the training segments, their associated activities, and rules of thumb to maintain engagement, check operators' understanding, and manage intuitive beliefs.

5.6 Pilot Training Implementation Procedure

One week before the training, operators accessed the pre-training homework. Results from the homework informed final adjustments to the training material to better address areas where operators struggled in the interlock procedure. Operators participated in the cause-and-effect training on dealing with trips and interlocks on January 26, 2024, from 10 AM to 12:30 PM. As previously noted, multiple sessions were held to accommodate operators' schedule. Due to time constraints relating to this thesis project's timeline, evaluation and reflection of this thesis project will focus on the first pilot session and its participants.

The training started with a brief introduction to the topic, agenda, and learning objectives. This was done to set operators' expectations on the training and provide tools for operators to monitor their learning performance (Edmonds & Pusch, 2022). Next, the trainers began the homework discussion. Aligned with suggestions by Van Merriënboer and Kirschner (2017), this session aimed to challenge operators' intuitive knowledge and cognitive strategies regarding interlocks and trips. Strategies included comparing answers with experts and peers, receiving clarifying questions from BTL training team members, providing counter-examples, and explaining to operators the benefits of alternative approaches to encourage mindset rewiring (Van Merriënboer & Kirschner, 2017). Before discussing the first LT (LT1), operators were directed to and asked to study the interlock flowchart. During the full demonstration of LT1, BTL training team members instructed operators to follow along using the interlock flowchart. They were prompted to reflect on how the demonstrated procedure differed from their usual approach, fostering self-monitoring and challenging inaccurate intuitive cognitive strategies if present (Van Merriënboer & Kirchner, 2017). The training progressed to LT2, where operators had more autonomy in problem-solving. To mimic operators' daily dynamic, they were encouraged to collaborate with fellow operators to discuss solutions. A short break was given before LT3 commenced. LT3 was dealt similarly to LT2.

The training session culminated with LT4, where operators tackled a complex scenario without assistance from the BTL training team (note that they still have access to flowcharts and how-to guideline documents). Due to technological constraints, LT4 was done by operators verbally describing their desired actions while a training team member navigated the simulator accordingly. Due to time limitations, only one set of operators could complete LT4. To ensure the remaining two operators could still benefit from the exercise, they were grouped and told to observe their peers' performance and to provide feedback. One BTL training team member and the researcher evaluated performance using the assessment rubric. After completing LT4, discussions were done that encouraged operators to share insights and reflect on their learning experience. In the discussion, operators were also asked to share the training aspects that they liked and disliked, which would contribute to the evaluation of the pilot training.

Following the training session, an internal debriefing session was conducted between the researcher and the BTL training team members to evaluate both the successful elements and areas for improvement in the training.

5.7 Pilot Training - Result

The effectiveness of the pilot study was evaluated in two parts: (a) assessing the impact of the design recommendations based on the 4C/ID model on operators' learning and (b) determining the suitability of the design recommendations for the BTL team as a whole. This evaluation incorporated various measures, including the results of the pre-training homework, live training observation, performance on the final LT, feedback from operators collected during post-training discussions, and input from BTL training team members during the debriefing session.

5.7.1 Operators' Performance

In the pre-training homework, operators struggled most with procedural part-task sequences related to unfamiliar areas of the DCS, particularly the detailed cause-and-effect screen. However, they performed well in other familiar phases of the part-task sequences, such as finding information in faceplates and identifying trip lists. Additionally, they demonstrated sufficient ability to list the high-level steps required to solve LT1.

Observation of the online classroom training revealed a positive trend in operators' performance in procedural phases to solve interlocks. Initially, substantiating the homework result, operators often paused during unfamiliar phases of the procedural steps, as they considered their decision and consulted the procedural document. However, with each repetition of the LTs, operators became more adept at identifying their next steps. Their critical thinking skills also improved over time. Initially, operators would interpret DCS readings at face value (e.g., "The trip is on because there is a high-level pressure in the valve"). However, as the training progressed, they began considering the tangible impact of trips and interlocks on plant processes, taking them one step closer to being able to solve interlocks independently (e.g., "[high level of pressure] is caused by a blockage … it can cause the barrel to be damaged").

By LT4, operators displayed increased confidence in their answers, transitioning from uncertainty (e.g., Ending sentences with "I think" or "maybe?") to assertiveness (e.g., "Now we bypass the trip"). They also provided answers that were more in-depth, with better understanding of how their decision would impact the plant's processes (e.g., "No [to bypassing the trip]. If we bypass [the trip], it will cause a blockage"). This indicated growth from the concise, high-level steps they provided in the homework. They remained composed, demonstrating no signs of panic, stress, or frustration, even when tackling more complex LTs. Using the scoring rubric for LT4 (see Appendix I for the detailed scoring rubric), it was observed that as a group, operators possessed a "Good" grasp of dealing with interlocks. They achieved "Good" ratings for all learning objectives except the last one, "Operators can independently apply their new knowledge in other situations." During LT4, operators received two guiding hints from the BTL training team without requesting them. As trainers' oversight caused this, the grade for the last objective was not factored into the final operators' performance classification.

5.7.2 Operators' Learning Experience

The observation indicated strong engagement from operators, who readily responded to random questions during the training. In the brief post-training discussion, operators expressed satisfaction with various aspects of the training, finding the learning objectives clear and the topic relevant, and particularly enjoying learning through examples. One operator commented, "It was good [learning] with the scenario examples."

Operators acknowledged the training's relevance, recognising the importance of "thinking before they act" when dealing with interlocks. They admitted to having overlooked the detail screen of the cause-and-effect page, not understanding how it could support their job obligations. "We learned new things," one operator said. Their performance in LT4 cemented this understanding, as operators now recognize the importance of the detailed screen in providing contextual information to resolve interlocks more effectively. Most operators intended to use the flowchart and DCS guidelines daily.

5.7.3 BTL Training Team Learning Experience

The training also served as a "train the trainers" opportunity for the BTL training team members. This experience demonstrated their ability to design and implement a pilot training based on the recommended design deliverables. They showed openness to collaborating, discussing, learning, and modifying their teaching approach according to the suggested design guidelines. The experience enhanced their understanding and confidence in creating and conducting future practical training sessions. One member noted, "We never made learning objectives before; I understand it is very important." Another mentioned, "I did not get the guideline before we did this pilot … now I see how everything falls into place." They also exhibited stronger pedagogical skills, effectively utilising the rules of thumb in the trainer's guideline procedural document to ensure engagement, managing intuitive beliefs, monitoring understanding, on-the-fly scenario complexity adaptation, and providing appropriate support while demonstrating a high level of domain knowledge. Here are several examples of how the training team members guided operators: asking probing questions that encouraged elaboration (e.g., in response to a surface-level answer from operators, "ok, but what does high level mean to the plant? What causes it?"), offering contextual hints (e.g., "We are on maintenance when this trip is on. Can we bypass it, or should we solve the interlock?"), giving real-life anecdotal examples (e.g., "This happens once in Finland…"), correcting errors subtly (e.g., "Hm, you are forgetting something").

The BTL training team struggled the most in displaying restraint in giving support, frequently giving hints to operators before they could fully engage with the material. Moving forward, team members need to embrace operators' uncertainty and encourage group discussions to foster independent skill development (Chen, 2020).

5.8 Pilot Training - Conclusion

The pilot training aimed to assess the learning effectiveness of the suggested design recommendations based on the 4C/ID model for the new operators' training program and its suitability for the BTL team. Discussions and observation of operators' performance indicate that the implementation was successful. The training structure aided operators in becoming more familiar with the domain, and the training format was well-received, aligning with operators' learning style preferences. Additionally, the overall training creation and implementation process received approval from the BTL training team.

The pilot training effectively addressed the identified problem areas of the current training programme by implementing the design recommendations. Real-life scenarios were carefully chosen to ensure that the training featured relevant content and skill exercises aligned with operators' daily tasks. Their enthusiastic approach to higher complexity tasks demonstrated that the exercise complexity aligned well with operators' current skill and knowledge levels, leading to significant skill improvement (Faber et al., 2023; Tomlinson et al., 2003). Notably, operators displayed increased confidence and independence during the sessions, indicating a reduced reliance on the BTL team. While the current outcome is encouraging, it's important to recognise that similar results may not be readily replicated with new operators given the differences in learner demographics. The experienced participants likely benefited from their time working in a pyrolysis plant, which could explain their quicker understanding and confidence in handling scenarios. Nonetheless, the suggested design guideline aligned well with the growth trajectory envisioned by the BTL team, demonstrating that effective training could be achieved through the use of online platforms and simulator software, offering flexibility and cost-effectiveness

The experience of designing and implementing the pilot training bolstered the confidence of the BTL training team in the viability of using the suggested design guideline to develop a comprehensive training program. As a result, the team is now ready to proceed with the complete design of the new operators' training program.

5.8.1 Lessons Learned for Future Implementation

Future improvements in designing and implementing training sessions include a more thorough assessment of operators' ability levels before deciding on task sequencing. For example, PTS was included in the pre-training homework because the team assumed that operators might struggle to complete a whole task immediately. However, operators have demonstrated forward-thinking skills, often answering one step more than needed in the part-task sequence. Moving forward, whole tasks should be championed. If part-task sequencing is necessary, backward chaining with snowballing will provide learners with examples and models of the whole task, aligning with established principles (Van Merriënboer & Kirschner, 2017).

In creating supportive information, especially strategic flowcharts, ensure that relevant rules of thumb are added. In the pilot training, BTL team members would share helpful rules of thumb for dealing with interlocks (e.g., "when bypassing in cause-and-effect screen, make sure that it does not bypass any other modules not related to interlock"). However, these were not documented in the interlock flowchart. Future iterations should integrate these rules into relevant flowchart phases to ensure consistency, completeness, and equal opportunity for all operators to succeed when using the flowchart (Faber et al., 2023; Van Merriënboer & Kirschner, 2017).

The BTL training team could enhance their pedagogical skills by improving their ability to probe for more information during training sessions. There were times when operators said something interesting (e.g., when asked how they felt about the pre-training homework, one operator said, "Yeah, we learned some new things"), which can be explored to further develop operators' metacognition by encouraging self-elaboration (Van Merriënboer & Kirschner, 2017). This improvement can be incorporated into the trainers' guideline document as a rule of thumb.

5.9 Process Reflection

In this portion, we will discuss the general positive and improvable aspects of the thesis project. On the positive side, smooth communication and teamwork were observed among the researchers, relevant project stakeholders, university supervisors, and SMEs throughout the design process. This collaborative effort led to a smooth design recommendation process, as SMEs and stakeholders helped mitigate biases to ensure careful consideration of various perspectives. This enhanced the accuracy and effectiveness of the recommended designs. Key factors contributing to this success include open communication, clear management of expectations, and collaborative accountability among team members. The small size of the BTL team and its client company likely facilitated this smooth collaboration by reducing bureaucracy and enabling easy access to all stakeholders. Future design research should prioritise establishing a solid rapport with various parties and stakeholders to ensure smooth progress across all phases of the design timeline.

This project may have experienced scope creep, becoming too large or complex to manage effectively within the given timeframe and resources. Applying McKenney and Reeves' generic model for conducting design research in education (2018) and Van Merriënboer and Kirschner's 4C/ID model (2017) was valuable for the researcher's growth as an educational psychologist. Regardless, future projects of a similar nature and timeframe could benefit from focusing more on delving into the granularity of the ten steps of 4C/ID. For example, focusing on the skill hierarchy of plant operators could lead to a more robust list of essential knowledge, attitudes, and performance assessments, which will also help create operators' development pathways and remuneration. The breadth of this thesis project is wide, yet there are clear areas where the next step is to go more in-depth to further build the classroom training modules.

5.10 Product Reflection

The primary objective of this project is to offer advisory services to BTG Bioliquids regarding their current new operator's training program. The analysis activities, design process, and pilot implementation all indicate a promising outlook for using deliverables created from this thesis project.

In a professional setting, the importance of maintaining design soundness is often overlooked (McKenney & Reeves, 2018). However, this project underscores the significant impact that following a well-established instructional design model can have in real-life applications. The pilot training phase provided a valuable opportunity to witness first-hand how applying the 4C/ID model can enhance operators' learning experiences and outcomes. It is gratifying to see the 'puzzle pieces' fall into place, so to speak. From identifying the problem area to finding suitable solutions and finally witnessing these solutions being implemented with the help of the chosen instructional design model. Moreover, it is rewarding that this project successfully balanced instructional rigour with meeting the stakeholders' needs and barriers. It is encouraging to witness the BTL training team members gradually demonstrate increased buy-in as they recognize the benefits and feasibility of the design with each step of the process. Following theoretical models does not have to be burdensome; they can lead to practical solutions.

Nevertheless, it is understood that the findings from the pilot implementation are not yet comprehensive. Without conducting a complete iteration of the new operators' training, it is challenging to gauge the full efficacy of the recommended design guideline. It would be ideal to develop a complete module for the new operators' training programme and deliver it to actual new operators to gain further insights into its effectiveness. However, initial feedback suggests promise for the final design recommendations, with stakeholders favouring the chosen design. This indicates the potential success of future design and implementation of the recommended new operators' training programme.

Reference

Alexander, P. A. (2019). The art (and science) of seduction: Why, when, and for whom seductive details matter. Applied Cognitive Psychology, 33(1), 142–148. https://doi.org/10.1002/acp.3510

Bandura, A. (1969). Social-Learning Theory of Identificatory Processes. In D. A. Goslin (Ed.), *Handbook of Socialization Theory and Research* (pp. 213-262). Chicago, IL: Rand McNally & Company

Bloom, B. (2012). The Taxonomy of Educational Objectives. In *Springer eBooks* (p. 3311). https://doi.org/10.1007/978-1-4419-1428-6_6027

Chen, Y. (2020). Dialogic pathways to manage uncertainty for productive engagement in scientific argumentation. *Science & Education*, *29*(2), 331–375. https://doi.org/10.1007/s11191-020-00111-z

Chryssolouris, G. (2006). Manufacturing Systems: Theory and practice. In *Springer eBooks*. https://doi.org/10.1007/0-387-28431-1

Covey, S. R. (1997). *The Seven Habits of Highly Effective People: Restoring the Character Ethic*. Macmillan Reference USA.

Dawe, S. (2003). Determinants of Successful Training Practices in Large Australian Firms. *National Centre for Vocational Education Research*. https://eric.ed.gov/?id=ED474845

Earl, L. (2007). Assessment - a powerful lever for learning. *Brock Education Journal*, *16*(1). https://doi.org/10.26522/brocked.v16i1.29

Edmonds, G., & Pusch, R. (2022). Guidance for Designing Asynchronous Learning Experiences for Adult Learners. *Region 5 Comprehensive Center*.

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*, *62*(1), 107–115. https://doi.org/10.1111/j.1365-2648.2007.04569.x

Faber, T., Dankbaar, M., Kickert, R., Van Den Broek, W. W., & Van Merriënboer, J. (2023). Identifying indicators to guide adaptive scaffolding in games. *Learning and Instruction*, *83*, 101666. https://doi.org/10.1016/j.learninstruc.2022.101666

Fiorella, L., & Mayer, R. E. (2021). Principles for reducing Extraneous Processing in Multimedia Learning. In *Cambridge University Press eBooks* (pp. 185–198). https://doi.org/10.1017/9781108894333.019

Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. *American Psychologist*, *56*(3), 218–226. https://doi.org/10.1037/0003-066x.56.3.218

Frèrejean, J., Van Geel, M., Keuning, T., Dolmans, D., Van Merriënboer, J. J. G., & Visscher, A. J. (2021). Ten steps to 4C/ID: training differentiation skills in a professional development program for teachers. *Instructional Science*, *49*(3), 395–418. https://doi.org/10.1007/s11251-021-09540-x

Fryling, M. J., Johnston, C., & Hayes, L. J. (2011). Understanding Observational Learning: an interbehavioral approach. *The Analysis of Verbal Behavior*, *27*(1), 191–203. https://doi.org/10.1007/bf03393102

Hinds, P. (1999). The curse of expertise: The effects of expertise and debiasing methods on prediction of novice performance. *Journal of Experimental Psychology: Applied*, *5*(2), 205–221. https://doi.org/10.1037/1076-898x.5.2.205

Hinds, P., Patterson, M. D., & Pfeffer, J. (2001). Bothered by abstraction: The effect of expertise on knowledge transfer and subsequent novice performance. *Journal of Applied Psychology*, *86*(6), 1232–1243. https://doi.org/10.1037/0021-9010.86.6.1232

Jonassen, D. H. (1997). Instructional design models for well-structured and III-structured problem-solving learning outcomes. *Educational Technology Research and Development*, *45*(1), 65–94. https://doi.org/10.1007/bf02299613

Kaiser, K. (2009). Protecting respondent confidentiality in qualitative research. *Qualitative Health Research*, *19*(11), 1632–1641. https://doi.org/10.1177/1049732309350879

Kolb, D. A. (1983). *Experiential learning : Experience as the source of learning and development*. http://ci.nii.ac.jp/ncid/BB1767575X

Könings, K. D., Van Zundert, M., & Van Merriënboer, J. J. G. (2019). Scaffolding peer-assessment skills: Risk of interference with learning domain-specific skills? *Learning and Instruction*, *60*, 85–94. https://doi.org/10.1016/j.learninstruc.2018.11.007

Konstantinidou, A., & Nisiforou, E. A. (2022). Assuring the quality of online learning in higher education: Adaptations in design and implementation. *Australasian Journal of Educational Technology*, *38*(4), 127–142. https://doi.org/10.14742/ajet.7910

Lim, J. H., Reiser, R. A., & Olina, Z. (2008). The effects of part-task and whole-task instructional approaches on acquisition and transfer of a complex cognitive skill. *Educational Technology Research and Development*, *57*(1), 61–77. https://doi.org/10.1007/s11423-007-9085-y

Lu, Y., Hong, X., & Xiao, L. (2022). Toward High-Quality Adult Online Learning: A Systematic Review of Empirical Studies. *Sustainability*, *14*(4), 2257. https://doi.org/10.3390/su14042257

Mayer, R. E., & Fiorella, L. (2021a). Introduction to multimedia learning. In *Cambridge University Press eBooks* (pp. 3–16). https://doi.org/10.1017/9781108894333.003

Mayer, R. E., & Fiorella, L. (2021b). Principles for managing essential Processing in Multimedia Learning. In *Cambridge University Press eBooks* (pp. 243–260). https://doi.org/10.1017/9781108894333.025

Mayer, R. E., Heiser, J., & Lonn, S. (2001). Cognitive constraints on multimedia learning: When presenting more material results in less understanding. *Journal of Educational Psychology*, *93*(1), 187–198. https://doi.org/10.1037/0022-0663.93.1.187

McKenney, S., & Reeves, T. C. (2018). Conducting educational design research. In *Routledge eBooks*. https://doi.org/10.4324/9781315105642

Merrill, M. (2002). First principles of instruction. *Educational Technology Research and Development*, *50*(3), 43–59. https://doi.org/10.1007/bf02505024

Mills, C., D'Mello, S. K., Lehman, B., Bosch, N., Strain, A. C., & Graesser, A. C. (2013). What Makes Learning Fun? Exploring the Influence of Choice and Difficulty on Mind Wandering and Engagement during Learning. In *Lecture Notes in Computer Science* (pp. 71–80). https://doi.org/10.1007/978-3-642-39112-5_8

Mulders, M. (2022). Vocational training in virtual Reality: A case study using the 4C/ID model. *Multimodal Technologies and Interaction*, *6*(7), 49. https://doi.org/10.3390/mti6070049

Pekrun, R., Lichtenfeld, S., Marsh, H. W., Murayama, K., & Goetz, T. (2017). Achievement Emotions and academic performance: Longitudinal models of reciprocal effects. *Child Development*, *88*(5), 1653–1670. https://doi.org/10.1111/cdev.12704

Roussos, M., Johnson, A., Moher, T., Leigh, J., Vasilakis, C. A., & Barnes, C. (1999). Learning and Building Together in an Immersive Virtual World. *Presence: Teleoperators & Virtual Environments*, *8*(3), 247–263. https://doi.org/10.1162/105474699566215

Rowe, A., & Fitness, J. (2018). Understanding the role of negative emotions in adult learning and achievement: A Social Functional perspective. *Behavioral Sciences*, *8*(2), 27. https://doi.org/10.3390/bs8020027

Sartori, R., Costantini, A., Ceschi, A., & Tommasi, F. V. (2018). How do you manage change in organizations? training, development, innovation, and their relationships. *Frontiers in Psychology*, *9*. https://doi.org/10.3389/fpsyg.2018.00313

Skiba, R. (2020). Application of adult learning principles to high risk equipment operations training. *ECE Official Conference Proceedings*. https://doi.org/10.22492/issn.2188-1162.2020.41

Stadnicka, D., Litwin, P., & Antonelli, D. (2019). Human factor in intelligent manufacturing systems - knowledge acquisition and motivation. *Procedia CIRP*, *79*, 718–723. https://doi.org/10.1016/j.procir.2019.02.023

Stewart, R. F., Benepe, O. J., & Mitchell, A. (1965). Formal planning: The staff planner's role at start up (No. 250). *California: Stanford Research Institute*.

Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. *American Journal of Evaluation*, *27*(2), 237–246. https://doi.org/10.1177/1098214005283748

Timotheou, S., Miliou, O., Dimitriadis, Y., Sobrino, S. V., Giannoutsou, N., Cachia, R., Martínez-Monés, A., & Ioannou, A. (2022). Impacts of digital technologies on education and factors influencing schools' digital capacity and transformation: A literature review. *Education and Information Technologies*, *28*(6), 6695–6726. https://doi.org/10.1007/s10639-022-11431-8

Tomlinson, C. A., Brighton, C. M., Hertberg, H. L., Callahan, C. M., Moon, T. R., Brimijoin, K., Conover, L. A., & Reynolds, T. D. (2003). Differentiating instruction in response to student readiness, interest, and learning profile in academically diverse classrooms: A Review of literature. *Journal for the Education of the Gifted*, *27*(2–3), 119–145. https://doi.org/10.1177/016235320302700203

Turki, M. A., Mohamud, M. S., Masuadi, E., Altowejri, M. A., Farraj, A. I., & Schmidt, H. G. (2020). The Effect of Using Native versus Nonnative Language on the Participation Level of Medical Students during PBL Tutorials. *Health Professions Education*, *6*(4), 447–453. https://doi.org/10.1016/j.hpe.2020.11.001

Van De Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in Teacher–Student Interaction: A Decade of research. *Educational Psychology Review*, *22*(3), 271–296. https://doi.org/10.1007/s10648-010-9127-6

Van Merriënboer, J. J. G. (1997). *Training complex cognitive skills: A Four-Component Instructional Design Model for Technical Training*. Educational Technology.

Van Merriënboer, J. J. G., Clark, R. E., & De Croock, M. (2002). Blueprints for complex learning: The 4C/ID-model. *Educational Technology Research and Development*, *50*(2), 39–61. https://doi.org/10.1007/bf02504993

Van Merriënboer, J. J. G., Kester, L., & Paas, F. (2006). Teaching complex rather than simple tasks: balancing intrinsic and germane load to enhance transfer of learning. *Applied Cognitive Psychology*, *20*(3), 343–352. https://doi.org/10.1002/acp.1250

Van Merriënboer, J. J. G., & Kirschner, P. A. (2017). *Ten steps to complex learning: A Systematic Approach to Four-Component Instructional Design*. Routledge.

Van Merriënboer, J. J. G., & Sweller, J. (2005). Cognitive Load Theory and complex Learning: recent developments and future directions. *Educational Psychology Review*, *17*(2), 147–177. https://doi.org/10.1007/s10648-005-3951-0

Vandewaetere, M., Manhaeve, D., Aertgeerts, B., Clarebout, G., Van Merriënboer, J. J. G., & Roex, A. (2014). 4C/ID in medical education: How to design an educational program based on whole-task learning: AMEE Guide No. 93. *Medical Teacher*, *37*(1), 4–20. https://doi.org/10.3109/0142159x.2014.928407

Vygotsky, L. S. (1978). *Mind in Society: the development of higher psychological processes*. https://ci.nii.ac.jp/ncid/BA03570814

Yang, H., & Farley, A. (2019). Quantifying the impact of language on the performance of international accounting students: A cognitive load theory perspective. *English for Specific Purposes*, *55*, 12–24. https://doi.org/10.1016/j.esp.2019.03.003

Yardley, S., Hookey, C., & Lefroy, J. (2013). Designing whole-task learning opportunities for integrated end-of-life care: a practitioner-derived enquiry. *Education for Primary Care*, *24*(6), 436–443. https://doi.org/10.1080/14739879.2013.11494214

Zeng, G., Chen, X., Cheung, H. Y., & Peng, K. (2019). Teachers' growth mindset and work engagement in the Chinese educational context: Well-Being and Perseverance of Effort as Mediators. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.00839

.

Appendix A

Operators Analysis Survey Questions

Table 2

List of questions for operators' current-state analysis survey

Question	Answering method	Answer options
Demographic question		
What was your prior experience / educational background before joining [insert plant name] as an operator?	Select multiple	a. Process operator b. Machine operator c. Relevant vocational education background d. Other (text elaboration)
Please state the years of your work experience	Select multiple	a. Less than 1 year b. 1-2 years c. 2-3 years d. 3-4 years e. More than 5 years
Questions for operators who joined the new operators' training		
Which training topic did you struggle with?	Select multiple	a. Basic personal and plant safety b. Pyrolysis process description for sections of the plant (such as Dryer, Biomass dosing, Reactor sand system, etc) c. Pyrolysis plant maintenance d. Introduction to DCS Screen e. Pyrolysis oil application f. Steam system g. Training with a process

		simulator h. Other (text elaboration)
What skills are still missing after the initial training with BTG Bioliquids?	Select multiple	a. Basic personal and plant safety b. Understanding of pyrolysis processes for sections of the plant c. Pyrolysis plant maintenance d. Introduction to DCS e. Alarm troubleshooting/problem solving f. Other (text elaboration)
What did you like about the original training with BTG Bioliquids?	Open question	
What did you dislike about the original training with BTG Bioliquids?	Open question	
What do you think can be added to the original training to prepare you for your day-to-day job as a plant operator?	Open question	
Questions for operators who did not join the new operators' training		
What kind of training (provided by Pyrocell) did you receive to be able to properly operate the plant?	Open question	
How long was your training	Open question	

period (provided by Pyrocell) prior to being able to operate the plant independently?		
Compared to your colleagues who did take part in the original BTG Bioliquids training, do you feel that you are missing knowledge / information relevant to operating the plant?	Yes/No	
Please elaborate on what relevant knowledge/information you think was missing	Open question	
General questions		
What is your preferred way of learning?	Select multiple	Online class Offline class/classroom training Instructional video Textbook / manual Training with Process Simulator Work Instructions On the job training Other
In your opinion, how well can you operate the plant independently with your current level of knowledge and experience?	6-points Likert scale	1 = Not at all; 6 = Very well
How are you currently doing your learning to better prepare yourself to operate the plant?	Select multiple	a. Shadowing/working together with a more experienced operator b. Requesting for BTG

		Bioliquids' guidance c. Studying the operating manual d. Asking the internet (googling, etc) e. Internal knowledge sharing f. Trial and Error g. Taking additional training courses h. Other (text elaboration)
With your experience of operating the plant, what prior information do you think is crucial to learn to make your experience better?	Select multiple	a. Basic personal and plant safety b. Understanding of pyrolysis processes for sections of the plant c. Pyrolysis plant maintenance d. Understanding the DCS screen e. Alarm troubleshooting / problem solving f. Other (text elaboration)

Appendix B

Codes and Variations of the New operators' training's Problem Areas

Table 3

Overview of the coding scheme for data analysis

Code and Definition	Variation	Unit of Analysis	Freq.
Contextual Information Background information of the training and operators' job desk	Current state training initiatives and outcome Plant operators' daily obligations	"Training was mainly done offline. Operators are divided into two groups. Theory in the morning. In the afternoon, one group trains with the simulator, the other group goes to the site, and we mix that up daily."	31
Areas of Improvement Identified core issues of current training programme iteration	Novel information and its implications Classroom training content Classroom training assessment & exercise Operators' dependency Training methods and tools	"The [recall] questions at the end of training modules is a waste of time … I like it when [BTL training team] explains [real] problems and show me how to solve [them]"	75
Design Boundaries Existing boundaries that are present	- Technology - Trainers - Past experiences &	"At the end of the day, the training duration is in the hands of [BTL's]	55

internally and externally in relation to the training programme	documentation - Operators' background - Client relations	client."

Table 4

Transformation of coding scheme through the thesis project

Codes and Variations	Iteration Review 1	Iteration Review 3 - Final Coding Structure
- **Contextual Information** - **Areas of Improvement** - **Design Boundaries**	Contextual Information - Current state training initiatives and outcome Areas of Improvement - Novel information and its implication - Content Depth - Knowledge transfer: - Exercise Appropriateness - Operators Dependency: - Training method Design Boundaries - Technology - Trainers - Past experiences & documentation - Operators' background - Client relations	Contextual Information - Current state training initiatives and outcome - Plant operators' daily obligations Areas of Improvement - Novel information and its implications - Classroom training content - Classroom training assessment & exercise - Operators' dependency - Training methods and tools Design Boundaries - Available technology - Current initiatives - Trainers - Past experiences & documentation - Operators' background

	- Client relations

Appendix C

Expected Ideal Performance for New Operators

Table 5

Breakdown of expected ideal performance of new operators post new operators' training

Constituent Skill	Ideal Performance
General	a. Demonstrate clear communication with team members b. Curious and inquisitive when faced with unfamiliarity c. Receptive to direction when dealing with unfamiliar procedures
Safety	a. Familiar with the safety protocols of the plant b. Responsible for their own safety
Plant Operation	a. Familiar with how to read the condition of the plant (from DCS readings and alarm) and decide on a course of action accordingly b. Can follow set procedures to complete routine tasks and activities and solve recurrent alarms c. Able to find root causes of nonrecurrent issues and alarms d. Familiar with the plant production process that they can be directed to solve/fix complex nonrecurrent issues
Plant Maintenance	a. Familiar with the procedures that they can be directed to complete recurrent tasks b. Familiar with the procedures that they can be directed to solve/fix nonrecurrent tasks

Appendix D

Design Guideline for Online Pre-Training

Pre-training packet introduction

Aim:

- Introduce new operators to the concept of pyrolysis, the pyrolysis process, the physical structure of the plant, software that's used to operate the plant, and basic safety procedures.
- Operators start building a skeleton of high-level, generic information on which they can hang more complicated information later in their training journey
- Operators show awareness, understanding, and can remember the information given during this segment of training
- Prepare operators for higher-level of learning in the classroom training segment

Pre-training packet modules

Opening remarks to the pre-training packet

a. Open the pre-training

   "Welcome to the pre-training packet! This online course is designed to provide you with a solid foundation in understanding the crucial aspects of operating a pyrolysis oil plant …"

b. Learning objective

   "In this online course, you will get a wide-scope introduction to the basic knowledge that goes into pyrolysis plant operation."

   "You will learn about the fundamental workings of the pyrolysis oil plant. Gain insights into the plant's structure and functions. Understand the nature and significance of pyrolysis oil."

   "You will explore the Distributed Control System (DCS) software used to operate the plant. Familiarise yourself with the user interface and functionalities."

   "You will be made aware of the essential safety measures. Understand the protocols and guidelines for ensuring a secure operating environment"

c. Learning goal

   "After completing this pre-training packet, you should have a solid foundation of information of knowledge needed to operate a pyrolysis plant. This basis of understanding will be further explored in the classroom training."

d. Structure of training
   "This course is comprised of three training modules: Introduction to the pyrolysis plant, Introduction to the DCS, and Introduction to safety"
   "Each module concludes with a quiz to assess your understanding."
   "It is projected that the pre-training packet can be completed in around 3 hours. You have the flexibility to finish the online training at your convenience, but completion of this pre-training packet is required to join the classroom training commencement."

Introduction to the plant

e. Opening remarks
   i. Learning objective
   ii. Learning goal
   iii. Self-reflection ("Do you know anything about the process of creating biofuel?"; "Have you ever seen the inside of a factory before? See if you can spot similarities and differences between it and the pyrolysis plant."; etc)
f. What is pyrolysis?
   i. Introduction to pyrolysis
   ii. Introduction to biofuel
   iii. Usage of biofuel
   iv. Role of BTG Bioliquids in biofuel creation
g. Pyrolysis process
   i. High-level description of how BTG Bioliquids' plants produce biofuel
h. Plant tour
   i. Taking new operators on a tour around the plant.
   ii. Explain what each component/section of the plant does. What each hardware does.
   iii. Make sure it follows the pyrolysis process as described in the previous sub-module
i. Quiz

i. Tests operator's memory and understanding of biofuel, pyrolysis process, and structure of the plant

j. Closing remarks
    i. Summary
    ii. Further reading
    iii. Self-reflection ("How do you think this information will help you in your role as an operator?"; "Do you have any questions?")

Introduction to DCS

k. Opening remarks
    i. Learning objective
    ii. Learning goal
    iii. Self-reflection ("Have you ever worked with a DCS before? See if you can spot similarities and differences between it and the DCS used in the pyrolysis plant."; etc)
l. What is DCS?
    i. What does the DCS do
    ii. Importance of DCS
m. DCS tour
    i. Show each page in the DCS "tree" and what they represent. What activity/process happens on each page and what connects one to another
    ii. Relate it to the pyrolysis process shown in the previous module
    iii. Relate it to the real-life section of the plant
n. DCS features
    i. Introduce the buttons in the DCS and what they do
    ii. Introduce the parameters readings and their purpose
    iii. Identify recurring symbols of the DCS
    iv. Relate it to the real-life hardware in the plant
    v. Introduce "second level features" that operators may encounter in the DCS (e.g., alarms, faceplate, symbol changes). Explain their purpose and what they mean in terms of the pyrolysis process. Note: Keep it simple and high-level, and give examples to elaborate on the introduction

o. Quiz
    i. Test operator's memory and understanding of DCS screens, features, and symbols. Relate it to real-life hardware and plant sections.
    ii. Test operator's memory and understanding of the implications to changes in certain features/symbols.
p. Closing remarks
    i. Summary
    ii. Further reading
    iii. Self-reflection ("How do you think this information will help you in your role as an operator?"; "Do you have any questions?")

Introduction to safety

q. Opening remarks
    i. Learning objective
    ii. Learning goal
    iii. Self-reflection ("From what you've seen, what personal safety gear do you think you'll need to work safely in the plant?"; "What do you think are the emergency barriers set to protect operators?"; etc)
r. Personal protective gear
    i. Describe the different working conditions that exist within the plant
    ii. Demonstrate what personal protective gear is recommended to be used in each condition and why
s. Emergency procedures
    i. Introduce the emergencies that operators may encounter. What they are, how they look, and what might cause them
    ii. Demonstrate how to enact emergency procedures according to the situation
    iii. Explain the safeguards installed to protect operators from danger and how they do so
t. Quiz
    i. Test operators' memory and understanding on how to properly use personal protective gears according to their work conditions

   ii. Test operators' memory and understanding on emergency procedure scenarios

u. Closing remarks
   i. Summary
   ii. Further reading
   iii. Self-reflection ("How do you think this information will help you in your role as an operator?"; "Do you have any questions?")

Closing remarks to the pre-training packet

v. "If you have any questions, drop by the Teams environment and we will answer it!"
w. Reminder of where operators can find additional information
x. "See you on the [date for classroom training]"

Appendix E

Design Guideline for Classroom Training

Classroom Training introduction

Aim:

- Using whole-task practice to introduce and familiarise new operators with the daily tasks and activities of a pyrolysis operator
- Instilling confidence in new operators by practising real-life scenarios in a safe and controlled environment
- Instilling independence with gradually reduced support from the training team
- Instilling analytical thinking skills through increasingly challenging real-life problem-solving scenarios
- Instilling good communication habits through group exercises and real-life scenario roleplays
- By the end of this segment, operators should display part of the knowledge, attitude, and performance of the *junior operator* level.
- Preparing new operators for the more demanding, less controlled environment of on-the-job training segment

Classroom training modules

Learning Module 1

Demonstration of "the ideal day in the life of an operator"

New operators watch a video that shows a typical day in the life of an operator.

Aim:

- Gives an overall image of what's expected of them in their job

Activities:

- Watch the video
- Group discussion to check understanding/giving feedback

Suggested learning materials to be prepared:

- Video script & storyboarding
- Video shoot & editing

Content shown in the videos:

- Operators entering the plant and preparing for the day
- Monitoring the DCS
- Solving alarms
- Filling work permit
- Putting on safety gear
- Brief daily round around the plant
- Safely doing simple maintenance/physical actions in the plant
- Communicating with other operators/BTG Bioliquids team/plant manager/maintenance team
- Shift handover

Learning Module 2

Get involved in operating a pyrolysis plant in an ideal day

New operators get the chance to try out the activities as seen in the video.

Aim:

- Taking informational content and latent knowledge given to new operators during previous parts of the training and putting it in real-life situations.
- Delve into more detail at how to do essential activities in a day of operating a pyrolysis plant.
- Allowing operators to have hands-on practices in a safe and controlled environment

Activities:

1. Reintroduce the DCS
    a. Knowledge quiz on the DCS
2. Introduction on alarm
    a. Alarm severity identification quiz (I.e., low, medium, high severity)
    b. Alarm type identification quiz (I.e., informative vs warning vs alarm)

3. Refresher on safety procedures
4. Daily operators round simulation
5. Team communication roleplay (group discussion to check understanding/giving feedback)

Recommended information given

- Supportive
    - A deeper dive into the DCS (e.g., comparing DCS to P&ID, more detailed explanation of flow or processes using the DCS, etc)
    - Alarm introduction
    - Completed work permits to serve as examples in the work permit exercise
    - Checklist of daily operators round
- Procedural
    - Types of alarm graphic
    - Personal protective gear poster

Suggested learning materials to be prepared:

- Content capture
    - Live DCS recording
    - Captures of different types of alarm happening
    - Video, series of pictures, or VR for daily operator's round simulator
- Graphic design
- Create quiz environments
- Presentation slides

Learning Module 3

Dealing with alarms that lead to routine, simple DCS actions

New operators are introduced to the cues and indicators that would lead towards routine, simple DCS actions.

Aim:

- Building on the operators' skills of DCS monitoring and DCS operation
- Familiarising operators with identifying the cues and indicators for routine activities

- Introducing operators to more in-depth knowledge of the plant's process

Activities:

- (If needed) Introduction to the background knowledge of plant processes and interaction needed to complete the DCS actions
- Study the general flowchart for conducting this type of routine actions (limit to simple)
- Exercise in completing routine DCS actions
    - Demonstration on identifying alarms/cues
    - Demonstration of the actions to take based on said identification
    - Group exercise in completing routine, simple DCS actions
        - Study and use the manual/guideline for the exercise scenario to complete the action
- Group discussion to check understanding/giving feedback

Recommended information given

- Supportive
    - General knowledge of plant processes related to task
    - General information on plant module interactions related to task
    - Routine action flowchart (simple)
- Procedural
    - How-to guideline in navigating DCS for routine actions (simple)

Suggested learning materials to be prepared:

- P&ID
- Screenshot of DCS
- Presentation slides

Description to help in deciding on scenarios:

- The process of reaching a solution is always the same, or the solution itself is always the same
- Routine (always happens every x hour or x days)
- Consistent (if the reading shows x, do y)
- DCS action can be completed from the control room

Example scenario:

- Routine operators' procedure
    - Starting the burnout
    - Starting the condenser cleaning device
    - Cleaning Pyrolysis Oil coolers
- Operating the dryer
    - Starting the dryer
    - Setting the biomass storage vessel level
- TBA

Learning Module 4

Dealing with alarms that lead to routine, simple combination actions (DCS and physical actions)

New operators are introduced to the cues and indicators that would lead towards routine, simple actions that combine both DCS manipulation and physical actions in the plant.

Aim:

- Building on the operators' skills of DCS monitoring
- Familiarising operators with identifying the cues and indicators for routine activities
- Introducing operators to more in-depth knowledge of the plant's process
- Combining the contextual skill of DCS manipulation with physical action to complete routine activities

Activities:

- (If needed) Introduction to the background knowledge of plant processes and interaction needed to complete the routine actions
- Study the general flowchart for conducting this type of routine actions (limit to simple)
- Exercise in completing routine combination actions
    - Demonstration on identifying alarms/cues
    - Demonstration of the actions to take based on said identification
    - Group exercise in completing routine, simple combination actions

        - Study and use the manual/guideline for the exercise scenario to complete the action
- Group discussion to check understanding/giving feedback

Recommended information given

- Supportive
    - In-depth knowledge of plant processes related to task
    - In-depth information on plant module interactions related to task
    - Routine action flowchart (combination)
- Procedural
    - How-to guideline in navigating the DCS and doing the physical routine actions (combination)

Suggested learning materials to be prepared:

- P&ID
- Screenshot of DCS
- Content capture of locations or conditions in the plant relevant to the scenarios for extra context
- Mock-up of hardware that can be used for classroom learning. Or, if not possible
    - Video of how to deal with the actual hardware
- Presentation slides

Description to help in deciding on scenarios:

- The process of reaching a solution is always the same, or the solution itself is always the same
- Routine (always happens every x hour or x days)
- Consistent (if the reading shows x, do y)
- To solve it, operators need to change something on the DCS and also do something to the hardware

Example scenario:

- Routine operators' procedure
    - Pyrolysis oil truck loading and unloading

- Cleaning Extra Pyrolysis Oil Heat Exchanger, HE-438
- Change the big-bag with ashes from the filter
- Change the big-bag with sand from the boiler
- Clean the pyrolysis gas nozzle
- CA-641/843 calibration ABB pH measurements
- AT-902 calibration Brukert pH measurements
- Change Filter Bags Oil Filters
- Clean Filter Mesh Oil Heat Exchanger Filters
- Check condensate steam sample corner
- Make-up water supply by truck/IBC

- First-line maintenance
  - Replacing stuffing boxes
- TBA

Learning Module 5

Introduction to monitoring: Dealing with simple alarms and DCS indicators

New operators are tasked to monitor the DCS during an uneventful moment in their shift.

Aim:

- Applied practice for new operators to quickly get familiar with the core skill of operating (I.e., DCS monitoring and alarm solving)
- Hands-on practice in solving simple alarms
- Familiarising operators in using the alarm logbook
- Building operators' confidence in operating the plant

Activities:

- Study the general flowchart to solve this type of alarm
- Exercise in monitoring DCS and solving simple alarms
  - Demonstration on how to monitor the DCS
  - Demonstration on solving simple alarms
  - Group exercise in solving simple alarms
    - Study and use the logbook to solve the alarm
- Exercise logging the alarm

    - Study a worked-out example
    - Group exercise in making new entries
- Group discussion to check understanding/giving feedback

Recommended information given

- Supportive
    - General knowledge of plant processes related to task
    - General information on plant module interactions related to task
    - Alarm flowchart (simple)
    - Worked out alarm logbook entry
- Procedural
    - Types of alarm graphic
    - How-to guideline in navigating DCS for alarms (simple)

Suggested learning materials to be prepared:

- P&ID
- Screenshot of DCS
- Presentation slides

Description to help in deciding on scenarios:

- Alarms/DCS changes can be solved from the control room
- Alarms can be solved by being ignored, or by changing set-points in consistent ways
- The process of reaching a solution is always the same, or the solution itself is always the same
- Low severity
- No time limit for solving the alarm
- Comes from all areas of the plant

Example scenario:

- AIC-1003 High alarm moisture content during ramping up of the dryer after burnout
- LI1130 High alarm biomass storage silo V1102
- Pyrocell is asked to make a list
- TBA

Learning Module 6

Dealing with alarms that lead to routine, complex combination actions (DCS and physical actions)

New operators are guided through the cues that would lead to routine, complex actions that combine DCS manipulation and physical actions in the plant.

Aims:

- Building on the operators' skills of DCS monitoring
- Familiarising operators with identifying cues and indicators for routine activities
- Introducing operators to more in-depth knowledge of the plant's process
- Practising operators' critical thinking skills

Activities:

- (If needed) Introduction to the background knowledge of plant processes and interaction needed to complete the routine actions
- Study the general flowchart for conducting this type of routine actions (full version)
- Exercise in completing routine, complex combination actions
    - Demonstration on identifying alarms/cues
    - Demonstration of the actions to take based on said identification
    - Group exercise in completing routine, complex combination actions
        - Study and use the manual/guideline for the exercise scenario to complete the action
- Group discussion to check understanding/giving feedback

Recommended information given

- Supportive
    - In-depth knowledge of plant processes related to task
    - In-depth information on plant module interactions related to task
    - Routine action flowchart (combination – complex)
- Procedural
    - How-to guideline in navigating the DCS and doing the physical routine actions (combination – complex)

Suggested learning materials to be prepared:

- P&ID
- Screenshot of DCS
- DCS simulator
- Content capture of locations or conditions in the plant relevant to the scenarios for extra context
- Mock-up of hardware that can be used for classroom learning. Or, if not possible
    - Video of how to deal with the actual hardware
- Presentation slides

Description to help in deciding on scenarios:

- Routine (always happens every x hour or x days)
- Consistent (if the reading shows x, do y)
- The starting step in the procedure is always the same
- The exact process to reach the outcome is not always the same
- It takes a fair amount of critical thinking to complete
- To solve it, operators need to change something on the DCS and also do something to the hardware

Example scenario:

- Routine operator's procedure
    - Burnout
    - Condenser (re-)fill from oil tank
- Operating
    - Heating up the plant
    - Shut down Trips and shutting down
    - Starting production from standby
    - Starting production from plant stop or safety shutdown
- Operating steam system
    - Start-up steam export
    - Steam export to stand-alone
    - Stand-alone to steam export

- First line maintenance
    - Refilling water glycol systems and venting
    - Pressurising water glycol system
    - Replacing condenser rupture discs
- TBA

Learning Module 7

On the topic of safety: How to identify, report, and deal with hazards?

New operators are exposed to scenarios where they must deal with differing levels of hazardous situations and how to ensure the safety of everyone working in the plant.

Aim:

- Building on the operators' skills of DCS monitoring
- Familiarising operators with identifying the cues and indicators for enacting safety procedures
- Training operators to react ideally when faced with hazards
- Practising operators' cause-and-effect way of thinking
- Strengthening operators' knowledge of the plant's P&ID
- Building operators' confidence in operating the plant

Activities:

- Viewing a video of an example scenario
- Study the general flowchart in dealing with hazards
- Exercise in dealing with hazards
    - Reporting aspect
        - Demonstration on identifying alarms/cues
        - Cause-and-effect discussion
        - P&ID identification
        - Work permit filling
    - Solving aspect
        - Demonstration of the actions to take based on the scenario at hand
        - Group exercise in dealing with hazards

        - Study and use the manual/guideline for the exercise scenario to deal with the hazards
    - Group discussion to check understanding/giving feedback

Recommended information given

- Supportive
    - Information on hazards
    - In-depth knowledge of plant processes related to task
    - In-depth information on plant module interactions related to task
    - Hazards flowchart
    - Worked out work permit
- Procedural
    - Hazard identification guideline
    - How-to guideline in dealing with hazards

Suggested learning materials to be prepared:

- P&ID
- Screenshot of DCS
- DCS simulator
- Content capture of locations or conditions in the plant relevant to the scenarios for extra context
- Mock-up of hardware that can be used for classroom learning. Or, if not possible
    - Video of how to deal with the actual hardware
- Presentation slides

Description to help in deciding on scenarios:

- Previously identified hazards per the history of the other pyrolysis plants
- No time crunches
- Doesn't require stopping equipment/pausing plant/stopping plant

Example scenario (5+):

- Explosion and fire hazards

- Intoxication
- Mechanical hazard
- Electrical hazard
- Hazards due to process temperature and pressure
- Hazards due to steam
- Hazardous materials: Pyrolysis oil, pyrolysis vapours, CO, Nitrogen, chemical dosing units, chemical waste

Learning Module 8

On the topic of safety: All about LOTOTO

New operators are exposed to scenarios where LOTOTO is needed.

Aim:

- Building on the operators’ skills of DCS monitoring
- Familiarising operators with identifying the cues and indicators for enacting safety procedures
- Introducing operators to LOTOTO

Activities:

- Introduction to LOTOTO
- Study the general flowchart to identify cues and complete LOTOTO
- Exercise in LOTOTO
    - Reporting aspect
        - Demonstration on identifying alarms/cues
        - Cause-and-effect discussion
        - P&ID identification
        - Work permit filling
    - LOTOTO aspect
        - Demonstration of the actions to take based on the scenario at hand (i.e., Stopping and starting equipment)
        - Group exercise in dealing with hazards

        - Study and use the manual/guideline for the exercise scenario to complete the exercise
- Group discussion to check understanding/giving feedback

Recommended information given

- Supportive
    - Information on LOTOTO
    - In-depth knowledge of plant processes related to task
    - In-depth information on plant module interactions related to task
    - LOTOTO flowchart
    - Worked out work permit
- Procedural
    - How-to LOTOTO guideline

Suggested learning materials to be prepared:

- P&ID
- Screenshot of DCS
- DCS simulator
- Content capture of locations or conditions in the plant relevant to the scenarios for extra context
- Mock-up of hardware that can be used for classroom learning. Or, if not possible
    - Video of how to deal with the actual hardware
- Presentation slides

Example scenario:

- Inspection of the reactor
- Inspection of the boiler
- Inspection of the steam drum
- Inspection of the boiler feed water pumps
- Inspection of the sand screw bearings C205/6/7/9 C302
- TBA

Learning Module 9

On the topic of safety: Emergency procedures

New operators are exposed to emergency scenarios and will be guided through the procedure on how to handle the plant in such a situation. This module will focus on how to handle the DCS in emergency procedures (physical emergency procedures should be done during on-the-job training).

Aim:

- Familiarising operators with the standard procedure when dealing with emergencies
- Building operators' confidence in operating the plant

Activities:

- Reintroduction of the emergency scenarios
- Study the general flowchart for emergency procedures
- Emergency procedures drill
    - Demonstration on identifying alarms/cues
    - Demonstration of the actions to take based on said identifications
    - Group exercise in dealing with emergency procedures
        - Manual/guideline may be used only at the beginning
- Group discussion to check understanding/giving feedback

Recommended information given

- Supportive
    - Information on emergency scenarios & procedures
    - In-depth knowledge of plant processes related to task
    - In-depth information on plant module interactions related to task
    - Emergency procedure flowchart
    - Worked out work permit
- Procedural
    - How-to emergency procedure guideline

Suggested learning materials to be prepared:

- P&ID
- Screenshot of DCS

- DCS simulator
- Content capture of locations or conditions in the plant relevant to the scenarios for extra context
- Mock-up of hardware that can be used for classroom learning. Or, if not possible
    - Video of how to deal with the actual hardware
- Presentation slides

Description to help in deciding on scenarios:

- Emergency scenarios where operators have to do critical DCS manipulation

Example scenario:

- Main power failure
- Fire alarm
- CO alarm
- Manual call points
- Explosion

Learning Module 10

Dealing with intermediate alarms and DCS indicators

New operators are exposed to more demanding alarms.

Aim:

- Hands-on practice in solving alarms
- Familiarising operators in using the alarm logbook
- Building operators' confidence in operating the plant

Activities:

- Study the general flowchart to solve this type of alarm
- Exercise in monitoring DCS and solving simple alarms
    - Demonstration on how to monitor the DCS
    - Demonstration on solving simple alarms
    - Group exercise in solving simple alarms
        - Study and use the logbook to solve the alarm

- Group discussion to check understanding/giving feedback

Recommended information given

- Supportive
  - In-depth knowledge of plant processes related to task
  - In-depth information on plant module interactions related to task
  - Alarm flowchart (intermediate)
  - Worked out alarm logbook entry
- Procedural
  - Types of alarm graphic
  - How-to guideline in navigating DCS for alarms (intermediate)

Suggested learning materials to be prepared:

- P&ID
- Screenshot of DCS
- DCS simulator
- Content capture of locations or conditions in the plant relevant to the scenarios for extra context
- Mock-up of hardware that can be used for classroom learning. Or, if not possible
  - Video of how to deal with the actual hardware
- Presentation slides

Description to help in deciding on scenarios:

- Alarms/DCS changes can either be solved from the control room or need operators to go into the plant
- Solutions for them are consistent (i.e., can be solved by following the logbook), but the steps to solve them are longer than the examples for simple alarms.
- Low to medium severity
- Either no time limit for solving the alarm, or there is one but not too short
- Comes from all areas of the plant

Example scenario (10+):

- Low level sand cooler

- Checking Level Switch
- TBA

Learning Module 11

How to deal with abnormal/nonroutine alarms?

New operators are guided through scenarios of alarms/issues that are not part of their routine or can't be solved with existing procedures. This prepares them to deal with problems, issues, or alarms that they cannot solve independently due to a lack of appropriate knowledge or experience.

Aim:

- Familiarising operators with the procedure on how to deal with alarms or issues that can't be solved by following procedures
- Building a habit of critical thinking and analytic mindset
- Strengthening operators' cause-and-effect knowledge
- Strengthening operators' knowledge of plant processes and component interaction
- Preventing misguided assumptions or shorthand when operating the plant
- Building the habit of documentation
- Building operators' sense of independence in operating the plant

Activity:

- Study the alarm troubleshooting general flowchart for this type of alarm
- Help request comparison exercise
- Exercise in dealing with 'out of league' alarms/issues
    - Demonstration on how to monitor the DCS
    - Demonstration on finding cause-and-effect
    - Demonstration on creating the help request
    - Group exercise in solving 'out of league' alarms
        - Cause-and-effect discussion
        - Study and use the manual/guideline for the exercise scenario and the help request examples to deal with the alarm
- Exercise in making new entry in the alarm logbook

  - Study a worked-out example
  - Group exercise in making new entries
- Group discussion to check understanding/giving feedback

Recommended information given

- Supportive
  - In-depth knowledge of plant processes related to task
  - In-depth information on plant module interactions related to task
  - Alarm flowchart (nonroutine)
  - Worked out alarm help request entry
  - Worked out alarm logbook entry
- Procedural
  - Types of alarm graphic
  - How-to guideline in navigating DCS for alarms (nonroutine)

Suggested learning materials to be prepared:

- P&ID
- Screenshot of DCS
- DCS simulator
- Content capture of locations or conditions in the plant relevant to the scenarios for extra context
- Mock-up of hardware that can be used for classroom learning. Or, if not possible
  - Video of how to deal with the actual hardware
- Presentation slides

Description to help in deciding on scenarios:

- Alarms/issues that are realistically going to be beyond the new operators' ability to solve independently, based on what they've learned so far

Example scenario (5+):

- TBA

Appendix F

On-the-job Training Checklist Template

Table 6

Checklist of routine actions that are to be learned during on-the-job training

No.	Skill	Observed a demo	Successful replication	Feedback
Safety				
	Emergency procedures drill	●	●	
	Personal protective equipment	●	●	
	CO	●	●	
	Fire alarm	●	●	
	Fire water	●	●	
Operating DCS				
	Stopping / shutting down the plant	●	●	
	Starting up the plant	●	●	
	Restart production/ operation	●	●	
	Cooling down the plant	●	●	
	TBA	●	●	
Emptying and filling systems				
	Emptying systems	●	●	
	Filling systems	●	●	
Routine operators' procedure:				
	Replace pyrolysis oil filters	●	●	
	Condenser (re-)fill from tank	●	●	

Make-up water supply by truck / IBC	●	●
Pyrolysis oil truck loading	●	●
Operator inspection rounds	●	●
Housekeeping	●	●
First-line maintenance		
Changing filters	●	●
Cleaning oil discharge	●	●
Handling materials - Raw materials	●	●
Handling materials - Liquids	●	●
TBA	●	●
Conducting analysis		
Biomass	●	●
Raw material	●	●
Pyrolysis oil	●	●
Boiler feed water and boiler water	●	●

Appendix G
Trainers' Guideline

"Create your own training" guideline:

1. Learners need analysis
    a. What topic do operators want to learn?
    b. What are they struggling with?

2. Design boundaries analysis
    a. Resource analysis
        i. How much time does BTG Bioliquids need? How much time do they have?
        ii. Who will present the training?
        iii. Does BTG Bioliquids have all the tools needed to complete the planned training?
    b. Methods analysis
        i. How will the training be conducted? (i.e., offline/online)

3. LT analysis
    a. What are the actual, real-life scenarios that are to be trained?
    b. How would you ideally complete the scenario?
    c. Where do you think operators will struggle in following the ideal solution?

4. Learning objective identification
    a. What skill(s) do you think are needed to successfully complete the LT?
    b. What skill(s) do you want operators to develop during the training?
    c. Create a learning objective(s) based on the identified skills that you want to develop
    d. Decide on performance objectives based on the list of learning objective(s).

5. Task structuring
    a. Decide the flow of the training. Which information goes first? Which real-life scenarios should operators learn first?

   b. Decide on the difficulty for each training segment
   c. Decide on the level of support for each training segment

REMEMBER:

- Don't give detailed how-to information before it's needed (they're not going to learn it otherwise)
- Start simple and slowly go to higher complexity
- Give a lot of support at first, and slowly take it away until operators can do the skill to the ideal level of independence

6. Knowledge and procedural information identification
   a. What knowledge is needed to be given prior to the training to raise operators' awareness for the topic?
      i. The "What". The background theory lays down a base knowledge for operators to hang more complex information later on. Example:
         1. What is it?
         2. How is it related to other procedures/section/component of the plant?
         3. Where is it?
         4. How does it look?
         5. What is in it?
   b. What are the specific procedures/step-by-steps that need to be followed to solve the LT?
      i. The "How". Information that operators only need when they're about to do the newly learned skills. Example:
         1. Procedures (flowchart)
         2. Operating manual
         3. Guideline
         4. Step-by-step checklist
         5. Tips and tricks
         6. Rules of thumb

7. Learning mode analysis
   a. What method is best to give operators new knowledge and information? Example:

i. Online learning environment
ii. Online classroom
iii. Offline classroom
iv. Video demonstration
v. Life demonstration

b. What method is best to do each planned training activity and exercises based on the real-life scenario(s)?

Example:

i. Online group collaboration
ii. Offline group collaboration
iii. Low fidelity simulation (using screenshots of the DCS)
iv. High fidelity simulation (using the simulator tool)
v. Low fidelity hands-on experience (using example of hardware in-class)
vi. High fidelity hands-on experience (on-the-job training)

8. Content creation

Based on the analysis so far, start creating the learning content for the training.

a. Based on the performance objective
   i. Formulate the learning goals in general ("after this training, you will be able to ___") and specific ("after this module, you will be able to ___")
   ii. Formulate the learning objective in general ("in this training, you will learn ___") and specific ("in this module, you will learn ___")
b. Based on the to-be-learned knowledge & information:
   i. Turn the required information into attractive learning content:
      1. Make presentation slides
      2. Design graphics / charts
      3. Design posters with rules of thumb / tips and tricks
      4. Make easy-to-read guidelines
      5. Shoot videos
      6. Record audio
c. Based on the to-be-learned real-life scenario
   i. Portray the scenario into safe-to-learn environment

1. Collect screenshots of scenarios
2. Program the simulator
3. Shoot demonstration video
4. Procure hardware for hands-on activity

d. Based on the need for self-assessment
    i. Write self-reflective questions for pre- and post-training

e. Based on the need for training evaluation
    i. Create pre- and post- training survey to measure operators' level of understanding
    ii. Create post-training satisfaction survey to monitor the effectiveness of the training

REMEMBER:

- Start simple. This also applies in designing the material for real-life scenario practices.
    - If you think operators are going to be confused or distracted with the complexity of the simulator, start with screenshots or show P&ID.

9. Run the training!

Appendix H

Pilot Trainers' Guideline

1. Introduction
    a. Training topic introduction
    b. Agenda
    c. Trainers' introduction
    d. Learning goal

2. Segment 1 – Homework discussion
    a. Question 1-4
    b. Ask operators how they completed question 5
    c. Flowchart introduction
    d. Demonstrate how to properly complete question 5
        i. Suggested question:
            1. "How do you think my demonstration differs from your answer?"
            2. "What do you think is the benefit of solving interlocks with this method?"

3. Segment 2 – Full Support Demonstration
    a. Scenario: There was a blockage between C303 and C304 and C303 stopped. Explain how to solve the blockage and how to manually start C303?
        i. Ask the operators to explain how they would solve the interlock in their current state
        ii. Explain the "normal state" of the equipment. What is the flow of production/how the equipment behaves when there is no trip/interlock?
        iii. Demonstrate how to solve the scenario using the flowchart, while explaining the steps along the way (i.e., about override modules/ownership, going through all interlocks conditions and trip conditions of C303, etc)
        iv. Group feedback
            1. Suggested question:
                a. "What do you think is different in the way you would solve the issue compared to how I just did?"
                b. "Let's summarise the exercise. What do you think is the key step in this procedure?"
                c. "Share an interesting insight that you picked up from the demonstration."
                d. "Are there any steps that you're still confused about?"

4. Segment 3 – Partial Support, Operators Try it Out
    a. Scenario: During maintenance, all the sand is in the combustor, and you want to fill the separator. How would you go about doing this? As you can see, C302 is

interlocked.
Discuss (i.e., let operators think of the answer but point them to the right direction if they're lost) with the operators to:

i. Explain the "normal state" of the equipment. What is the flow of production/how the equipment behaves when there is no trip/interlock?
ii. Solve the scenario using the flowchart. Ask operators to explain the steps along the way (i.e., about override modules/ownership, going through all interlocks and conditions for interlocks of C302, etc)
    1. Suggested question:
        a. When operators appear to do something wrong, give hints towards the correct answer instead of the answer right away. Example: "What could happen when X interlock is bypassed when it's not supposed to? How would it affect the other surrounding equipment?"
        b. When operators show inaccurate beliefs (i.e., skipped steps, jumps in cognition, taking wrong shortcuts), point them to the flowchart.
        c. When operators appear stuck, direct them to the supportive document or flowchart instead of telling them where to go right away. Example: "Where are you in the steps? Where are you in the flowchart? What should happen next? Where to go next?"
        d. Challenge operators to use critical thinking to imagine how the same action will differ in other conditions. Example: "What could happen when X interlock is bypassed during maintenance/production?"
        e. Encourage operators to think creatively. Example: "Are there any other way you think this interlock can be solved?"
iii. Group feedback
    1. Suggested question:
        a. "What do you think is different in the way you would solve the issue compared to how I just did?"
        b. "Let's summarise the exercise. What do you think is the key step in this procedure?"
        c. "Share an interesting insight that you picked up from the demonstration."
        d. "Are there any steps that you're still confused about?"
        e. "Are there any interlock cases that you want to go over with us?"

5. Segment 4 – No Support, Operators Try it Out
    a. Scenario: Replacing back-end bearing from C206.
    The plant is cooling down because the back end bearing from the C206 will be

preventively replaced (maintenance). The sand circulation is running, and the plant is almost completely cooled down.
Explain all the steps which are needed to inspect the back end bearing from C206? Hint: the cyclone must be emptied.
Ask operators to:

i. Solve the scenario using the flowchart. Ask operators to explain the steps along the way (i.e., about override modules/ownership, going through all interlocks and conditions for interlocks of C206, etc)
    1. Suggested question:
        a. Only help operators when they're 100% stuck. Give hints towards the correct answer instead of the answer right away.

ii. Group feedback
    1. Suggested question:
        a. "How do you think that went?"
        b. "What do you still struggle with?"
    2. Corrective feedback:
        a. What operators did right and wrong based on the rubric. Suggest further reading or activity to increase skill based on each operator's struggles.

6. Closing
    a. Repeat learning goal
    d. Training evaluation survey

Appendix I

Performance Assessment Rubric for Pilot Training Implementation

Table 7

Scoring rubric for the final LT of the interlock pilot training

Learning goal	Good	Partial	Poor
Operators know how to use the interlock flowchart procedure when dealing with interlock - Operators properly deal with module's ownership to prepare module for manual start	• Operators systematically followed the steps shown in the flowchart when dealing with interlock • Operators can use the flowchart to accurately change module ownership	• Operators partially (i.e., goes back and forth, skips a few steps) followed the steps shown in the flowchart when dealing with interlock • Operators can use the flowchart to accurately change module ownership	• Operators barely followed the steps shown in the flowchart when dealing with interlock • Operators cannot change any type of module ownership
Operators can thoroughly investigate the cause of interlocks by following the step-by-step guideline to navigate the DCS and gather information	• Operators thoroughly gathered information regarding the interlock by going through all the DCS screens shown in the supportive document • Operators show time and movement efficiency in	• Operators partially gathered information regarding the interlock by skipping a few of the DCS screens shown in the supportive document	• Operators barely gathered information regarding the interlock by skipping most of the DCS screens shown in the supportive document

	navigating between DCS screens to gather information		
Operators can think critically to determine the effect of their decisions when proposing solutions to interlocks	• Operators have good process knowledge to explain the 'why' and the 'what will happen to the plant' for all interlocks. • Operators propose 80-100% accurate steps to achieve the solution(s).	• Operators have adequate process knowledge to explain the 'why' and the 'what will happen to the plant' for most interlocks. • Operators propose 50-80% accurate steps to achieve the solution(s).	• Operators have poor process knowledge and can't explain the 'why' and the 'what will happen to the plant'. • Operators propose 0-50% accurate steps to achieve the solution(s).
Operators can independently apply their new knowledge in other situations	• Operators independently complete the task without the help of BTL training team.	• Operators complete the task with minor help from the BTL training team.	• Operators complete the task with heavy guidance from the BTL training team.