Preliminary Study to Differentiate Experts and Non Experts using Eye Tracking Technology

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Declaration

This work has not been previously accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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I would like to dedicate this work to my family and to my friends in CDT for their immense belief given to me during the journey.

Abstract

In a large industrial setting, a large amount of intangible knowledge in terms of experiences and intuitions is confined to experts, making it inaccessible for organisations to capitalise on by improving their workflow. If harnessed, experts' experiences and practices could help novice employees do their work efficiently. Understanding experts' experiences and intuition could help organisations maintain critical knowledge, known as tacit knowledge. Through tacit knowledge, organisations could aggregate learnings and co-operate to produce faster and more efficient results.

To further advance the concept of tacit knowledge, Swansea partnered with British Telecom (BT), a UK-based telecom service provider, to capture physiological data points and evaluate the possibility of AI in the collective management and distribution of tacit knowledge. Human-centred design methods were applied to identify the characteristics of experts and non-experts in lock-picking and Lego car robots. The methods used to capture gaze and physiological data, such as eye tracking technology, and wristband sensors were non-intrusive in nature. Gaze data was used for analysis as the physiological data displayed calibration error and limited correlation with gaze data.

The study indicates that user gaze in relation to the area of interest (AOI) provides an objective tool for measuring visual patterns. It also demonstrates the identification of experts and non-experts through their average fixation period and quality of attention. The application of the study lies in designing and developing machines that promote the growth of tacit knowledge in humans by capturing their work and workflow along with the relevant tacit knowledge. It is imperative to highlight and acknowledge that tacit knowledge has its dependence on the working environment, its interactions, and feedback.

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Chapter 1

Introduction

The greatest challenge for organisations that rely on information for their operations is not acquiring or storing the information but instead identifying employees' unique experiences that could be helpful to improve their operations. Such knowledge could give an organisation a competitive edge in the world [1]. With Covid-19, organisations have been facing challenges to preserve and update the learning practices of their employees as work becomes more remote and leads to changes in individuals' practices [2]. The unique perspective of employees is becoming essential to capture and identify for creating a knowledge management strategy [3]. In addition, organisations are looking for ways to improve training and development programs using employees' experiences and their know-how. Employees' experiences could also be thought of as tacit knowledge [4].

As per, Hungarian scientist Michael Polayani described tacit knowledge as, *"We know more than we can tell"*, meaning humans do many things in their daily life without being aware of their actions or why and how they did it [5]. They are unable to put their actions into words while explaining to others. As mentioned above, tacit knowledge is essential for organisations to create a knowledge repository to improve workflow [6]. Tacit knowledge is built upon experiences and continuous practising. People with tacit knowledge could be termed experts, as they have acquired the skill over time [7]. For example, expert craftsmen could make bamboo baskets without looking into documentation or assistance and make more baskets with different designs than their men as compared with novice craftsmen. The knowledge of craftsmen that resides in their minds to design multiple baskets with different designs in a short time is tacit knowledge [8]. In the airline industry, employees must maintain a high level of accuracy while performing their job. As per the give examples? What is tacit knowledge

case study of the U.S. airline industry, managers who acted based on past experiences and intuition gave the advantage to improve performance in the industry and did not solely rely on the procedures [9].

Before this tell the project brief given to us

To identify tacit knowledge, we conducted an empirical study examining experts' and non-experts' physiological data to identify tacit knowledge. Through the physiological data, we could identify patterns that describe how experts can be differentiated from non-experts.

Currently, the way to capture tacit knowledge is through workshops, focus groups, and seminars that give emphasis on storytelling [10]. We explored sensory data to identify tacit knowledge and extended the literature review by combining the think-aloud method while capturing sensory data. In the future, we shall be using the current methodology to capture the tacit knowledge of the telecommunications technicians working in British Telecom.

What we did?

1.1 Motivations

Digital twins, virtual (VR), and augmented reality (AR) provide technical support for field service operations [11, 12, 13]. These technologies provide real-world simulation to the workforce as training to improve their expertise without being present in the field [14]. Therefore the workforce is already aware of the real-world scenarios by making them ready for complex service operations. Peña-Rios et al. have explored the simulation of VR for the workforce, where VR simulators provide hands-on training for telecommunications technicians [15]. Different industries are adopting VR-based solutions. Another research highlights that safety training for the construction industry was developed using VR. This VR-based training simulator helps workers learn about electrical safety and prevent workplace hazards [16].

Existing technologies enable the workforce to learn the skills in a virtually simulated environment. However, the technology does not let them share their key insights or critical moments where they felt they could have done the task differently. VR-based simulations are better than video-based simulations as the former enables the training in a three-dimensional space. However, the question arises of how these VR solutions capture critical moments or intuition while working on the job. How do we develop a technology that could capture critical moments of new knowledge? We move in this direction of capturing tacit knowledge.

British Telecom (BT), the world's leading telecommunications service provider company. BT provides fixed-line services, broadband, mobile and TV products, and networked IT

Challenge

services. It faces the challenge of supporting decision-making and improving knowledge sharing within its workforce. Engineers, technicians, and other domain experts within BT have a wealth of knowledge about the systems, services, and equipment they interact with daily. This tacit knowledge is developed over a long time, initially through formal training but also refined and augmented by the experience of the individuals concerned. It is difficult to capture this knowledge through traditional means, such as written documentation, which defines the industry's challenge.

Tacit knowledge could help train other staff better, develop structured knowledge representations, refine behaviours over time, capture real-time interaction/maintenance of systems (particularly older/obsolete equipment), and support decision-making.

As an example to illustrate BT's challenge, look at the Fig. 1.1, which consists of a box used for providing a clipped boundary between the public network and the customers' internal fibre wiring [1]. DexGreen, a product company, developed Demarcation Box Customer Service Point (CSP), which is designed for household installations in the fibre to the house (FTTH) network[17]. This is used by BT technicians.

Figure 1.1: DexGreen, a product company, developed Demarcation Box Customer Service Point (CSP), which is designed for single-family and small multi-family installations in the fibre to the house (FTTH) network. It acts as a clipped boundary between the public network and the customers' internal fibre wiring [17]. This is used by British Telecom (BT) technicians.

[1]https://dexgreen.com/blogs/quick-guides/csp-demarcation-box-user-guide

The challenge in this scenario for BT engineers is the training - how could expert technicians who are well versed with using demarcation box CSP train novice technicians? One of the solutions could be for novice technicians to observe expert technicians on the job or watch a video of the expert or experts writing the steps involved in using the demarcation box. However, the challenge remains the same. Expert technicians are not able to share tacit knowledge.

1.2 Objective

The current study intends to understand how to differentiate the experts and non-experts based on physiological data. We chose activities that resemble the work done by the technicians in the telecom industry (see more in Section 3.2). The work done by technicians is broad, from tightening a screw to fixing baseband units to putting telecom wiring under the road. To understand skill acquisition, we employed the user's gaze and fixation duration, heart rate, and accelerometer data while performing the activities.

Eye tracking technology helps to interpret workplace functions and how people interact within them. Eye tracking allows insight into how skilled people perform their work and could be used to train others [18]. Experts or experienced users can assist in training novice or inexperienced users in their field. For example, expert workers in the construction industry could help novice workers improve hazard recognition, and safety awareness [19]. In the case of aircraft inspection, experts developed systematic search strategies for defect inspection in their work that eye tracking technology could capture [20].

From summarising the challenges and opportunities, we came up with the following research questions:

- **RQ 1:** How to identify, capture and store tacit knowledge while employees are working and without interrupting their workflow?
- **RQ 2:** What methods would be fruitful to use to capture knowledge that is embodied within the employees workplace?

To solve our research questions, we developed hypothesis:

- **H1**: Experts know what they are doing and hence their focus while doing the task would be more when compared with non-experts.

1.3 Overview

To fulfil the research question as written in Section 1.2 we undertook a exploratory research to find methods that could be used in the industrial setting. We started using wearable devices to capture physiological data that could, in return, help us find where to look for tacit knowledge. We did not find relevant data, but we concluded with a technique to differentiate experts and non-experts through gaze data.

1.4 Contributions

The MSc thesis attempts to demonstrate the idea of differentiating experts and non-experts based on gaze data. This research focuses on differentiating experts and non-experts as per physiological data. The main contributions of this work can be summarised as follows:

- Experts in lockpicking take less time to identify the task and hence spend less time. Expert has less fixations and they lookaway from the activity to feel the sensations.
- Expert has a better attentive stage, top-down mechanisms and covert attention.
- Eye tracking is a potentially useful tool to differentiate novices from experts in the domain.
- User gaze concerning the area of interest (AOI) eye tracking technology provides an objective tool for measuring visual patterns.
- Eye tracking is not equal to cognition but one step closer to making an expert's thought processes explicit and providing insight into how to guide learners.
- Based on the literature review, we could say that P02 exhibited skill-based behaviour where the participant already knew what was happening next. The rest of the participants exhibited rule-based behaviour as instructions were given to them in the format of the video, and based on that, they performed.

Chapter 2

Background

This chapter overviews the relevant work related to our research study. Our objective is to capture the tacit knowledge of the expert technicians working in telecom industry and transfer it to the non-expert technicians. The background is divided into six sections based on the nature of the problem: knowledge and management; proficiency in skills; tacit knowledge in different fields; use of physiological data; AI and tacit knowledge; trouble with capturing tacit knowledge.

The chapter starts with literature on knowledge and how it can be managed in different categories, then understanding proficiency in skill through different theoretical lenses, moving on to making ourselves aware of how tacit knowledge is captured in different fields, how physiological data is used by researchers in capturing tacit knowledge, then how artificial intelligence is used in the context of tacit knowledge and concludes with the section of the trouble in capturing tacit knowledge.

The literature review in this section is exhaustive but is instead representative of authors and experts with differing perspectives and backgrounds.

2.1 Skills and its relations to Tacit knowledge

For humans to live in the world, they require various abilities. When humans first evolved, they learned how to endure the harsh environment by creating tools and weapons from the materials [21]. They acquired skills in crafting arts, clothing, and shelter. The present technology era demands various skill requirements that call for advanced talents. The abilities also include listening, watching, and grasping in addition to doing things. These skills serve as the foundation for the social skills required to communicate with others and fit in with the social group.

Humans can adapt to the context where they live to cope with modern living. Depending on their work, they developed hundreds of technical and social skills [22]. The irony is that they would not be aware of those skills, that they have developed many skills, such as skills that require standing up, sitting, walking, running, and the ability to operate objects.

Humans' capabilities could be divided into proficient and less proficient or experts and non-experts. The question arises, How do some humans have more proficiency in doing the task while others have less? How to categorise something as proficient or less proficient?

As per the literature, the answer lies in having access to tacit knowledge. We shall be covering what tacit knowledge is in a later section (Section 2.1.2). Nevertheless, for now, if we assume that tacit knowledge is the answer to the above questions, then we need to go deeper to understand the length and breadth of the skill acquisition.

To illustrate the challenge we are trying to solve, let us take the example of baking a savoury in the home [1]. We all love savouries and enjoy eating them in a restaurant, but if we try to create them back home, they might not taste or appear the same as we ate them in the restaurant. What might the reason be? Even after following the recipe, the chef used, what is missing in the home when we bake? What is the secret ingredient? That secret ingredient has the magic to bind everything and gives the taste that we ate in the restaurant. That secret ingredient is **tacit knowledge**. The job of us researchers is to find what is the tacit knowledge that proficient humans have. Or does everyone has tacit knowledge and everyone is proficient?

Let us see another example of learning to ride a bike [2]. How did one learn to ride a bike? Was it a book or a video that helped to learn to ride? Did someone help to learn the tricks of riding a bike? Or one just tried and learned to ride a bike by trial and error? We could say that the combination of reading, watching and trying helped the person to ride a bike. This is the skill one has acquired, and by practising over time, one acquired experience. If one is out of touch with riding, one must practice riding again. By practising, learn to ride again.

The person had learned to ride a bike and has become proficient. As bike development evolved, bike gears came into existence and made the person less proficient. One has to learn to ride a bike with gears. One needs to ask someone for help or watch a video. How to change the gears? What are the advantages of gears? When riding up the hill, what

[1] https://www.wikihow.com/Make-Savoury-Muffins
[2] https://www.wikihow.com/Ride-a-Bicycle

gear does one need to put on? These are the new learnings that one has to take with the evolution of bikes with gears. Even after listening to somebody or reading, one needs to experience themselves to learn how to ride a bike on a mountain. Hence, the skills are acquired through intuitive experience-based wisdom (also called tacit knowledge) that is developed over time. Hence, the skill acquisition process is a continuous process where one tries to improve their proficiency.

2.1.1 Knowledge and its management

Knowledge is the central theme of the project that concerns us. Here we attempt to define the term limiting to the project interest. *Knowledge* could be defined as systematic information formed through judgments and experience [23]. *Knowledge* could also be defined as a series of information systematically arranged with a purpose [24]. Ancroi et al. described knowledge that could be broken into basic knowledge, using that knowledge to share with others and organising it [25]. Knowledge could be divided into *explicit* and *implicit* or *tacit* categories as shown in **??** [26]. *Implicit knowledge* is acquired by repetitive practicing of a skill that develops a 'know how' over the time. How things happen is implicit knowledge and is difficult to be codified. *Explicit knowledge* is acquired through reading books, articles, and procedures that could be codified, captured and accumulated.

Knowledge	
Explicit Knowledge	It may be shared with others using communication tools such as language and documents. (*know-about* / *know-that*)
Implicit or Tacit Knowledge	It cannot be articulated in words and is difficult to convey since it is situational and based on an individual's experience. (*know-how*)

Table 2.1: In this table, we have divided the knowledge into two categories. Our concern is with tacit knowledge, and to understand its complete perspective, we studied and compared it with other terminologies to differentiate the meaning.

Explicit knowledge refers to formal systems within an industry that defines product specifications and scientific formulas [27]. It could be best practices, and standards that help an organisation to operate. As per cognitive psychologists, it could be further divided into *declarative knowledge* where knowledge is based on the facts and procedures [28]. Declarative knowledge is also synonymous with explicit knowledge. The tasks and methods are defined or easier to tell to others: *What to do* is easier to communicate using declarative knowledge.

Tacit knowledge which cannot be codified or articulated by using common communication techniques could also be further divided into procedural knowledge [28]. *Procedural knowledge* helps to demonstrate how things happen. It is about *doing*, which is done by motor skills or needs mental skills, such as riding a bike, playing the piano and making art. However, it is not easy to share knowledge in words as if the knowledge is hidden within humans.

The following sub-sections take us into a deeper understanding of explicit knowledge and tacit knowledge.

2.1.2 Tacit knowledge

Tacit knowledge is the knowledge that cannot be articulated. As Michael Polanyi, 1997 mentioned, "can know but cannot tell" [5], meaning knowledge is not well understood by the research community [29]. It is easier to remember a stranger's face but how one remembers is difficult to put into words. This is like pattern recognition. Humans could recognise a pattern because of the gestalt principle but explaining patterns' constituents would be difficult to explain.

In other examples, often in successful teams, players who possess tacit knowledge about each other's game know intuitively how their peers are going to play, which improves coordination and series of smooth passes among them to succeed in a goal. Players read each other in advance what or how a team member is going to do or play.

Just after World War II, Gilbert Ryle addressed the Aristotle Society with the suggestion that philosophy had neglected a fundamental problem by typically addressing explicit knowledge ('knowing that') rather than the knowledge inherent in abilities ('knowing how') [30]. Ryle suggested that we 'know' more than we know about ourselves. Both Polanyi and Ryle pointed out the limitation of the scientific community towards knowledge and how knowledge is codified, and how knowledge is an embodied part of human learning.

2.1.3 Explicit Knowledge vs Tacit Knowledge

Tacit knowledge is learnt by doing, experiencing, teaching, and coaching, and it is not easy to transfer by writing or verbalising it. As opposed to explicit knowledge that can be written down, transmitted, and understood. As per Michael Polanyi, riding a bike, knitting a sweater, or karate is not just the knowledge one can learn from a book; these activities require more than oral or written form. It would be wrong to assume that explainable youtube videos are a form of tacit knowledge. Tacit knowledge could be acquired by practising that skill mentioned in the video and developing unique knowledge over the youtube video.

Explicit knowledge may be conveyed using formal and methodical language and is recorded in historical records such as libraries, archives, and databases. This information is readily communicated officially and methodically between individuals or from coach to athlete or athlete to athlete.

We shall use the example of sports to elaborate on the differences between explicit and tacit knowledge. In sports, for example, successful teams or players analyse their game statistics - what worked and what did not [31]. Possession statistics, positional duties of players, and how the best players performed are all compared. It is easy to identify each step leading up to the winning score using match statistics, but the question is whether players saw their steps occurring in real-time. Is it comparable to watching a game from the sidelines as it is to be a player on the field? Is it better to utilise statistics or *intuition* to determine the path of the game? Could this information lead to instinctual behaviour, causing the game to flow in a specific direction? For instance, a player who runs the ball on the last play deviates from the game plan or set play. This player may keep the other team guessing, culminating in a winning play.

Reading a book, discussing with a coach or team member, or researching the complexities of the sport may provide the player with explicit information. It is not about obtaining the information, but it also modifying the knowledge as per individual experiences. The argument here is whether intuition could lead to the formation of tacit knowledge and whether it differentiates the meaning between explicit and tacit knowledge. What leads to intuition? Do experiences influence intuition? It has been observed that intuition, gut-feeling are challenging to share in organisational settings as it helps to improve the workplace [32]. In medicine, intuition, experiences, and perceptions are essential in making clinical judgments but challenging to express to others in the medical profession [33].

These are questions that are getting explored and answers to these questions keep changing as per the context.

2.2 Proficiency in Skill: Understanding Human Performance

2.2.1 Skilled Performance

As per Fitts and Posner, skilled performance is a set of arrangements of activities to achieve a goal [22]. Access to a single piece of information or a jerk in the muscle are not examples of skilled performance. However, the set of arrangements to shoot a basketball or the consolidation of information in moving next move in a game of chess constitute skill. Thus, skill includes both a set of arrangements of movements and a set of arrangements of symbolic information. Spatial and temporal factors affect the development of arrangements or patterns in skilled behaviour. Let us take the example of holding a pencil. A pencil should be picked proportionately by the fingers so that pencil is grasped without any hindrance and moved in coordinated manner.

Similarly to calling somebody by their name, the variation in amplitude and the tone of voice used at the time determines whether that name is communicated correctly or not. Writing also involves a set of arrangements by the arm and hand muscles to write a name. Holding, speaking and writing are simple acts learnt over many years and have become part of the unconscious. These skills could be said that they are automatic in an adult. Nevertheless, it took a laborious time to acquire these skills.

Measurement of skill: The expertise of skill is measured by the accuracy and uniformity of critical processes involved in an activity [22]. For example, the shot made from half-court in the middle of an intense basketball game, the soloist's execution and the orchestra's synchronisation create a marvellous symphony, demonstrating skill proficiency. Even daily, the linguistic skills we apply to communicate with our peers and the use of symbolic skills in daily life demonstrate proficiency.

Sensory information and response movements are required to form a skilled behaviour. *Stimuli* and *feedback* are the components that help build a set of arrangements. Stimuli are the prompt that helps to form relevant information that arises from previous responses because of the reactions to those responses. Collectively these responses are called feedback. Stimuli and feedback is essential to have accuracy and uniformity to demonstrate a skilled behaviour.

The hindrance to feedback prevents performing a skilled behaviour. Prevent the smell of the curry from reaching the chief, and they would almost overcook the food. Playing loud music while driving on the highway could lead to miscalculations, inaccuracy or errors in predicting the road conditions and the car's direction. Delayed auditory feedback could lead to accidents. When the body's temperature rises, the body starts sweating, responding to the stimuli in the form of feedback. Hence feedback forms a critical component in making a set of arrangements.

Stimuli and feedback form the part of information processing that involves studying the human nervous system and transmission between humans and their environment. The skills mentioned in the above paragraphs could be put into information processing skills. These include identifying the information, speculation through the information, reduction of speculated information and creation or elaboration of information.

Let us consider a secretary who takes dictation and uses a typewriter for typing. During dictation, the secretary uses shorthand and transcribes it onto a typewriter. In this process, information is passed through dictation. That dictation was reduced to abbreviations and symbols and later transcribed into a letter through a typewriter. The secretary is now called a proficient typewriter as she can listen, comprehend and communicate properly using a typewriter.

Information reduction and information creation are two essential processes to keep in mind. Whether it is reduction or creation, human uses their memory to perform a skill using a stimuli-feedback loop. This theoretical perspective could be used to capture skills and discuss the implementation of transferring captured skills to others. The industry stakeholder, British Telecom, employs thousands of technicians who work on the field to deploy and fix wires and equipment. Few of these technicians have acquired proficiency in their skills while practising and working. We are engaged in understanding their proficiency: how they have become proficient in their work and what expertise they have developed that can be made explicit for others to develop.

2.2.2 Embodied Sensemaking: Use of skill, tool and environment

Rather than focusing on technology to capture tacit knowledge, we should focus on human beings and their bodies. We shall be exploring the connection between human bodies and tacit knowledge. As per Michael Polanyi, tacit knowledge cannot be documented and is difficult to express [5]. Then would it be correct to say that tacit knowledge is abstract, or is it a skill that the body acquires over time? Let us explore this in the following paragraphs.

The body could be thought of as such that it can perform skills in an environment using tools that affect others living in the environment and gets feedback from all these. This cycle of feedback with skills, environment, tools and others keeps on going with the body.

Skills that are developed in an **environment**, require **tools**. Tools could be hands, but various tools also become an extension of our body apart from hands. A human body does not exist in isolation. It is always in social interaction with **others**. A body with skills, bodies, environment, working tools, objects and interactions with others continuously talk, creating constant **feedback**. It means the feedback affects how people do their work as they start acting on that feedback, which changes the environment. That influences people's behaviour again. This has been one of the focus of the TEI-community and this literature is inspired by [34].

Skills: To understand tacit knowledge, we need to look at human bodies' skills. Every human being has enormous skills. Skills are physical that are learned over time to perform a particular action [35]. Skills are the ability to complete a particular task. Examples from daily life include skills - walking and biking. Humans have learnt how to walk and bike over a period and by practising repeatedly. Biking on a mountain compared to biking in the city demands different skills. The question comes then, how does one understand that different skills are needed to go biking on the mountain and the city roads? How should one pedal when going up the hill and when coming down from the hill? By practising, i.e., biking continuously and repeating the exact moment, the legs learn how to pedal accordingly on a steep hill or a downhill. Does the biker look at the legs to adjust the pedal power while biking? The biker looks at the road or front rather than down at her legs. That means the biker stops thinking about how her legs are moving. Another example is when someone walks up the stairs and thinks that person will trip and fall.

So, do humans stop thinking when they are acting? So, what are the skills? Skill is fluent and subconscious. That also does not mean that the biker is unaware of her surroundings. She is present at the moment but not thinking about how to pedal. If she thinks while riding a bike, she will fall.

Environment: Skills are developed in a certain environment. Biker, when she sees a rock comes, instead of crossing over the rock, she goes around the rock. Hence the human body tunes to the characteristics of the environment. The body gets tuned to the environment that they ask for. The human body responds to the environment, which means we move according to the environment. But when the body cannot move as per the environment, humans run into trouble. This leads to training and failing and, over time, repeating the same results in coherent relation with the environment.

Tools: This relationship does not happen only with bare hands, but tools also come into play in this relationship. Along with the body, it is also the tool humans use to build relationships. This relationship is about skillfully moving the body and skillfully using the tool. As one uses a tool over time, that tool becomes an extension of the body. Now, these tools are familiar to the person, and that person completes the tasks using them as if they are part of the body.

This theoretical framework helps us to focus on memory that the body has gained over the period to capture tacit knowledge.

2.2.3 Human Memory: Understanding Stimuli-Feedback

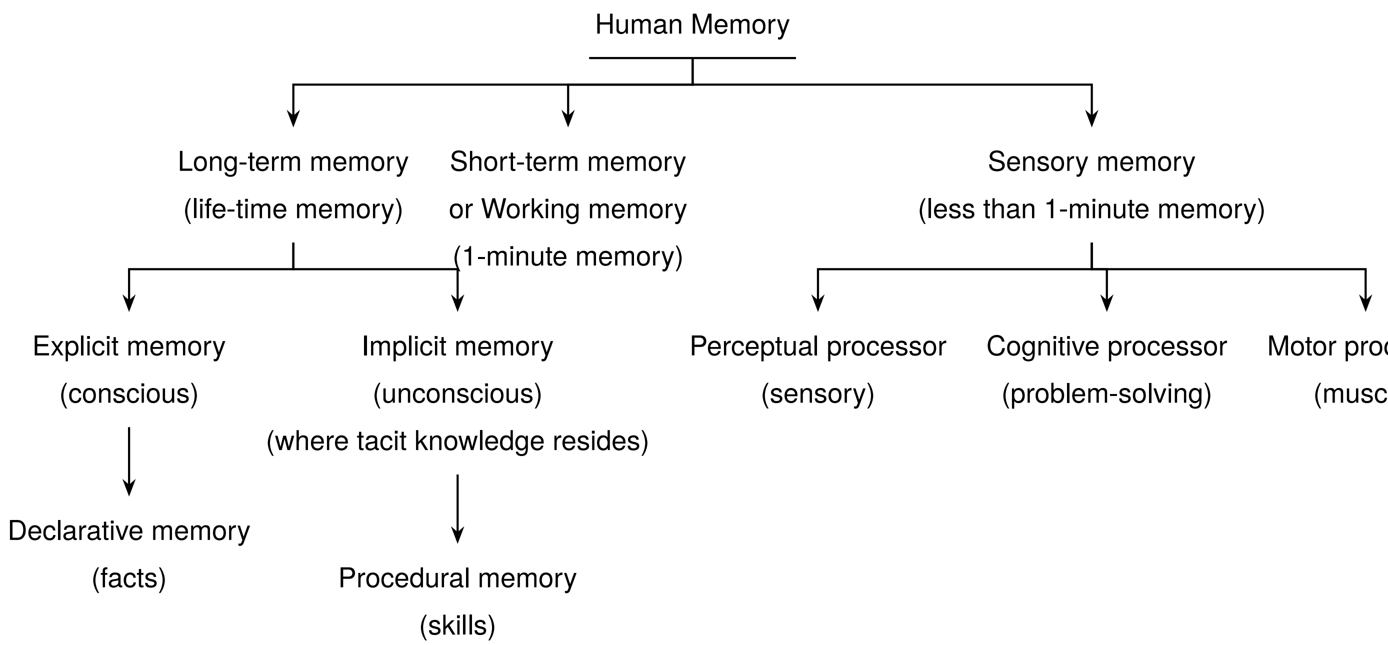
Memory helps to recollect past experiences and the leanings associated with them to take action. In this section, we seek to understand how human memory functions. The following understanding of memory comes from the school of thought, where it is assumed that the human brain is similar to processors and memories as described in the Von Neumann computer architecture [36].

According to Card et al, the human mind consists of three types of memories, Long-term memory, working memory, and sensory memory [37]. Long-term memory is the storage of information for a longer duration over time, where there is less need for practice to recollect information. In working memory, the information is stored temporarily for a shorter duration, where there is a constant need to practice to keep the information. Working memory interacts with long-term memory to store information for longer or to process information. Sensory memory is volatile, meaning information is stored for a short duration than working memory.

Long-term memory could be divided into explicit memory and implicit memory. Explicit memory is conscious, intentionally recollected for factual information, previous experiences and concepts. Implicit memory is unconscious memory that helps to build skills. For example, how to get dressed, eat, drive, ride a bike get stored. Once these skills are acquired, they are in the implicit memory, meaning they do not have to re-learn the skill each time.

Sensory memory has three processors through which the input enters the body. The stimuli or input coming to the body is converted into internal representation through the perceptual processor, stored in the sensory memory, and flows into working memory for sense-making. A cognitive processor is used for problem-solving that takes help from rules and structures stored in long-term memory. The motor processor helps in coordinating the information coming from the muscle. Stimuli enter from the perceptual processors loading into working memory, and the feedback(s) or the action(s) to the stimuli is sent through motor processors. In simple terms, this stimuli-feedback cycle goes on in a cyclic motion within the human body. In each cycle, the visual and auditory chunks present in the working memory are modified as per the information stored in the long-term memory. The human body responds as per the modified chunks of the working memory.

The human memory processor is explained through a tree-like structure **??**.



2.2.4 Understanding Expertise: Who is an Expert

When we want to capture an expert's tacit knowledge, we first need to understand how one becomes an expert. For this, we shall be using the Skills, Rules, Knowledge (SRK) framework proposed by Rasmussen in 1983 [38] and Dreyfus and Dreyfus model on skill acquisition model proposed in 1980 [39]. SRK framework explains how performance behaviour happens in human-machine systems through skills, rules and knowledge. In comparison, Dreyfus and Dreyfus provided a broader model of skill acquisition by dividing the acquisition into five stages - novice, competent, proficient, expert and master. Dreyfus and Dreyfus compliment SRK framework.

2.2.4.1 Skills, Rules, and Knowledge (SRK) Framework

SRK framework explained skilled-based behaviour, rule-based behaviour and knowledge-based behaviour.

Skilled-based behaviour (SBB): When the next steps are already known in a familiar situation, then skill-based behaviour comes into play. In this situation, the environment becomes a continuous parameter of the time-space relationship. A driver in the car, while driving, is aware of the inter-vehicular space, that is time-apace relationship. In SBB, the action of the user is not dependent on the motor response resulting from the stimuli-feedback loop. Rather the action happens because of the familiarity with the environment and already knowing what next needs to happen. During this behaviour, repetitive behaviour happens where motor responses are automated. Therefore, unconscious behaviour happens when there is familiarity with a situation.

Rule-based behavior (RBB): When the situation is familiar, but the actions are pre-decided, RBB comes into the picture. In this behaviour, rules are learnt through instructions or previous experiences and are then stored in the memory. When the action is needed, the rules are recalled from the repository and selected based on the situation. There are chances of errors and breakdowns in this behaviour.

Knowledge-based behavior (KBB): KBB is observed in a situation that is unfamiliar and there are no rules already stored in the repository for retrieval. A user in this unfamiliar environment reacts as per the goals and plans. The efficacy of the plans is tested by mapping the environment. There are chances that mapping could be wrong as it is an unfamiliar situation and previous experience might not support the current situation. This could also mean less exposure or learning is not given to complete the task. Hence this behaviour is error-prone.

2.2.4.2 Dreyfus & Dreyfus model of Skill Acquisition

The authors proposed a five-stage model of skill acquisition where they mentioned that skilful behaviour is observed in situational and non-situational. In the case of a non-situational, the situation is comprehended in a fragmented collection of hints and objects. For example, in the case of a novice basketball player, the location of the basket, court size, and basketball size are learnt in pieces. The lines and the semi-circles on the court are the cues of where to stand and how to take the shot. The skills are learnt in an 'if-then' fashion based on the hints learnt by the player.

In a situational scenario, a user is already aware of the situation, meaning she knows how to respond. Learning happens over time and through experiences. For example, the basketball player already knows at what speed the ball will come in front of him and how he would handle the ball to take another shot. All this thinking happens parallely while keeping in mind the other players of her team and the opponent team.

The Dreyfus model is like the SRK model as it uses all the three behaviours mentioned in the SRK model to build a five-stage model. KBB is used in a non-situational scenario where the user is not aware of the situation and learns skills through understanding the situation. At this stage, the user is novice and forms goals as per the scenario. As the user starts developing the meaning of the scenario, then she starts making the rules as well. This is RBB and happens in the intermediate stage of the SRK model. When the user becomes an expert, then that means she is now aware of the situation and knows what is going to happen. This stage takes the user to the SBB.

The Dreyfus model is based on the non-situational scenario and that describes five stages.

First, novice, where the user is making meaning using hints or features that are unclear in the starting. She has no idea what the situation is and tries to map the hints to make plans. Second, competent, where the user has developed the connections of the hints found in the first stage, and she can make a guideline for herself at this stage. Third, a proficient user can grasp the situation and is integrated well with the features present in the situation. The user starts prioritising what is essential to do in a situation. Fourth, experts, where the user has learnt the rules over time by practising. Now, she does not need to remember the rules. She can respond intuitively. Fifth, master, which is beyond expertise as per the model. The user can do more than the task at hand and find diverse ways of completing the same.

2.3 Capture Tacit Knowledge

Through seminars, focus groups and discussion, tacit knowledge has been attempted to capture. More than the capture, the organisation has focused on transferring tacit knowledge. Through these transfer sessions by the experts, the organisation attempts to document the tacit knowledge. This happens by storing presentations made by the experts in a central repository [40]. These methods have been traditional. We move into the computer science domain to find different ways to capture tacit knowledge.

2.3.1 Use of Physiological data to capture Tacit Knowledge

As discussed in the above section (Section 2.2), a user learns to complete a task, how skills are acquired for the tasks, and how she finds her way to accomplish the same. Hence we need to capture how a person completes a task, which could result in identifying the methods and making a list of best practices for the organisation. In this direction, visual attention and other physiological data have been found valuable in capturing the methods or how the user accomplishes the task.

We are particularly interested in capturing how the user does her tasks through wearable technologies. These technologies could include wristbands, eyeglasses, head-mounted sets, and finger rings. These technological devices are known as the Internet of Things (IoT). The applications of these devices range from the medical field and the airline industry to tracking employees' well-being. These devices consist of heart rate, temperature, optical, accelerometer and biosignals. Wearable devices are also non-intrusive in nature and could help to collect continuous measures of human behaviour. The readings shown by these devices don't need to be accurate but are a way to predict the human state of behaviour [41, 42].

The human body is a source of understanding the stimuli-feedback loop. The human body produces many signals that could help us to track human behaviour.

2.3.2 Wearable Technologies

The human body is a source of understanding the stimuli-feedback loop. The human body produces many signals that could help us to track human behaviour, as shown in Fig. 2.1. The human body needs inputs and outputs that help to run different machines present inside the body. These inputs are air inhalation, water and food intake, visual scenery, sounds, voices, and smell. Outputs are air exhalation, urine, sweat, blood, moisture, and temperature. Analysing these inputs and outputs could help us understand human behaviour's state, and wearable devices could measure these inputs and outputs. The Fig. 2.1 is showcasing various wearable devices used to capture these inputs and outputs.

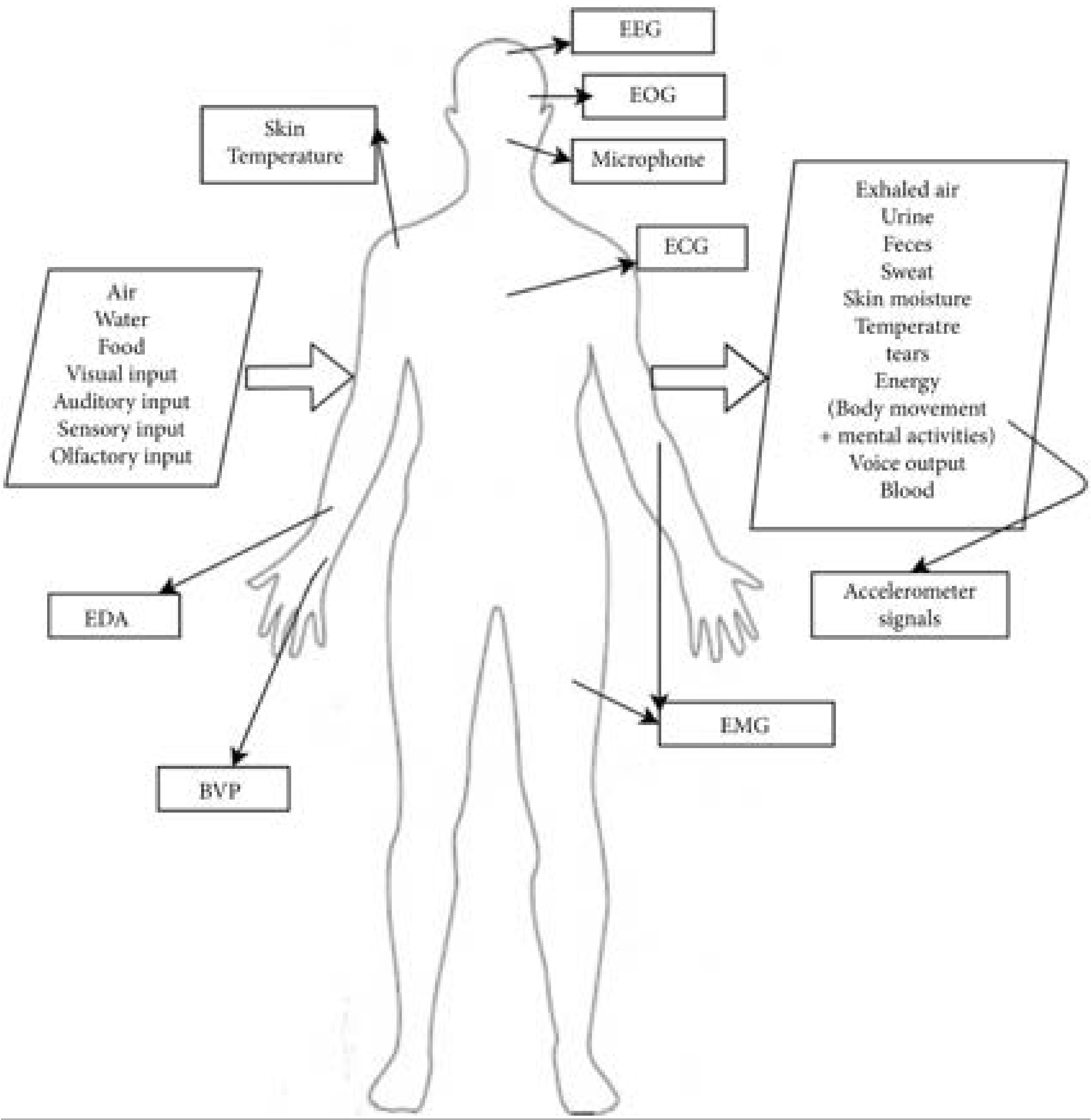


Figure 2.1: The human body is a source of understanding the stimuli-feedback loop. The human body produces many signals that could help us to track human behaviour. Image of the human body has been utilised from [43].

We shall explain these inputs and outputs related to skill performance and tacit knowledge. Literature highlights that skin temperature sensors could be used to measure stress. It is also known as galvanic skin conductance, which could record skin response in terms of the body's mental state [42]. Stress could mean, in terms of human performance - a way to find a solution to the problem, or it could tell at what point the user is having a problem to move forward in completing the task. Stress has both positive [44] and negative [45] impact on learning a skill.

Brain and muscle electrical activity could be measured by electrocardiogram (ECG), electroencephalogram (EEG) and electromyography (EMG) sensors could be used [46]. It has been seen that using brain activity, heart rate, and eyeblink rate could tell us the learning process and how much a user has learnt over time to the cognitive load. Emotional state of the construction workers could be identified using wearable EEG that could help to understand displeasure and excitement during the work for meaningful intervention by the management [47].

Emotions in the skill learning process could help to tell us where the user feels comfortable or excited. This could mean he is able to predict the next steps needed in task completion. Also, negative emotions could hint to us where is the cognitive burden coming up and where the breakdown is while doing the task. These points could then be compared with the other users and experts to find the key moments that could lead us to identify tacit knowledge.

Another study highlighted that by investigating brain activity, skill acquisition of medical professionals could be elicited [48]. Food preparation is also considered to be a skilled work. Food preparation could be used to understand smell as the input [49]. It has been observed that dogs learn through smell about their surroundings and become proficient in better navigation [50]. In the telecom industry, most of the time, technicians in the field have to work with the electrical wiring, and it is difficult to identify the problem by visual or sound the problem. Hence smell comes in handy to sense the problem, which helps in making better decision-making.

Eye Tracking: Eye-tracking, as an innovative technology, adds a new source of input to human-computer interactions in the form of individual visual experiences. Eye-tracking has been increasingly common and developed in recent years due to its potential uses in neuroscience [51], psychology [52], and computer science [53].

The eyes are the most developed sense. Furthermore, by understanding where people place their attention, we could start to understand how they perceive the world around them. Studying eye movements gives an understanding of how a person focuses their gaze, what they are paying attention to, and what influences their decision-making. Eye tracking will give insights that could not obtain in any other way because eyes do not lie.

Eye tracking is currently used to improve the user experience of an e-commerce website. Understanding better how to develop a point of sales materials. Eye tracking is unique in that it allows the researcher to become aware of the user's behaviour, which gives insights into visual search patterns and can, in turn, drive improvements in human performance.

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Eye tracking help in seeing through the eyes of the worker. Provides precise and accurate capture of visual attention. Data and videos can be used directly in training material and programs, and performance can be viewed live, shared, and discussed immediately.

Wearable eye trackers fit like a pair of eyeglasses and allow the participant to move around quickly. Eye tracking has been used in enhancing surgical training. For example, the German heart centre in Berlin has used eye tracking to observe how surgeons and perfusionists perform to help improve the training and evaluation of students [54]. Quality training for medical professionals is vital, but it can be difficult for experts to articulate the instinctive and subconscious elements of a procedure. Eye tracking captures an individual's gaze and provides a visual representation of where their attention's focused. As the medical professional mentioned that while doing the operation, it is not possible what made them make the decisions as that happens unconsciously during a procedure. But looking at the data collected by eye tracking while operating reveals a lot of unconscious thinking behind making the decisions. The centre used eye tracking to observe how surgeons and perfusionists perform to help improve the training and evaluation of students. They explored the question – of how to evaluate students' performance, as the teacher cannot see what they are thinking.

In aviation industry, eye-tracker was used to investigate pilot in-flight behaviors in simulated environment to aid decision-making process of pilots and to reduce the risk of loss of control in-flight. Eye-tracking helped researchers to develop pilots' information processing and their key characteristics while making decision [55].

Gaze data could help to understand how novice user learns and how she progresses. This could be in the inspection industry, where the technicians are needed to identify the specific targets in the aircraft industry [56].

Heart Rate:

In the 1970s, heart rates used to be recorded by chest straps, which caused inconvenience to the patient in observation [57]. As technology advances, new optical heart rate solutions have been developed that could be placed at convenient parts of the human body [58]. In a clinical study, stress was evaluated as a parameter to judge the level of preparedness in the medical operation. How did the students' stress vary during the training period and once the training had been compared? Stress data was correlated with students' personality data, where the authors analysed how the decision-making happened [59].

Chapter 3

Methods

Our study involving human participants was approved by the ethical board at our institutions and took place in Swansea, United Kingdom in August 2022. Our objective (as mentioned in Section 1.2) was to capture physiological data of the experts and non-experts to identify patterns. Another objective was to test the hypothesis of whether experts know what they are doing and hence looked somewhere else while doing the task. For this, we conducted the study in a controlled setting in the lab. We chose to track the users' eye-tracking and heart rate data while performing the given tasks. For tracking the data, we used Tobii Pro Glasses 2 for eye-tracking and Empatica E4 wristband for physiological data. The tasks given to the users were lock-picking and assembling the Lego car robot. We asked the users to think aloud about what they did while performing the study. We recorded their gaze data and physiological data for analysis.

The following sections will describe the experiment set-up to fulfil the objectives.

3.1 Pilot Study: To design meaningful experiment

Before understanding the experiment set-up, we conducted the pilot studies to test the metrics needed to accept to modify the hypothesis. The pilot study also helped to set the recruitment criteria and what length would be suitable for the user to participate. It also helped to decide the flow of the user study. For example, What considerations need to be taken while doing the user study? What equipment would be necessary to answer the research questions? How does calibration for the eye-tracking and heart rate sensor works? What trigger points need to be designed to differentiate the starting and the ending point? What metrics would be helpful to measure to answer the research question? What activities would be ideal for experimenting in the lab that resonates with the industry expectation? Which software would be needed to analyse the data? These were the questions that the pilot study helped us with.

3.1.1 Deciding activities

Decision process: Before finalising lock-picking and Festo. We experimented with a couple of activities. One such was the Festo machine as BT technicians use them in their work setting. It was decided to be used for user study but discarded this option as we could not get the experts of the machine in the given project timeline, see Fig. 3.1. Festo is a brand of industrial control and automation corporation that manufactures and distributes hydraulic, electrical, and mechanical technologies for manufacturing and process automation [60].

Figure 3.1: **Festo machine** was decided to be used for user study but **discarded** this option as we could not get the experts of the machine in the given project timeline. Fig. 3.1 Festo is a brand of an industrial control and automation corporation that Festo manufactures and distributes hydraulic, electrical, and mechanical technologies for manufacturing and process automation. Image of Festo machine has been utilised from [61, 62]

3D Wooden Brain Teaser Puzzle could be played by kids and adults and helps develop spatial thinking skills, see Fig. 3.2. The puzzle is difficult to explain to others if the person has understood how to solve it. One must take out all the wooden pieces and then put them back in a format. In this game, once the user understands the tricks, it is easier to solve. We wanted to capture how the person would explain the tricks she has learned to others. We discarded this activity due to the time crunch in ordering the kit. We may use it in future studies.

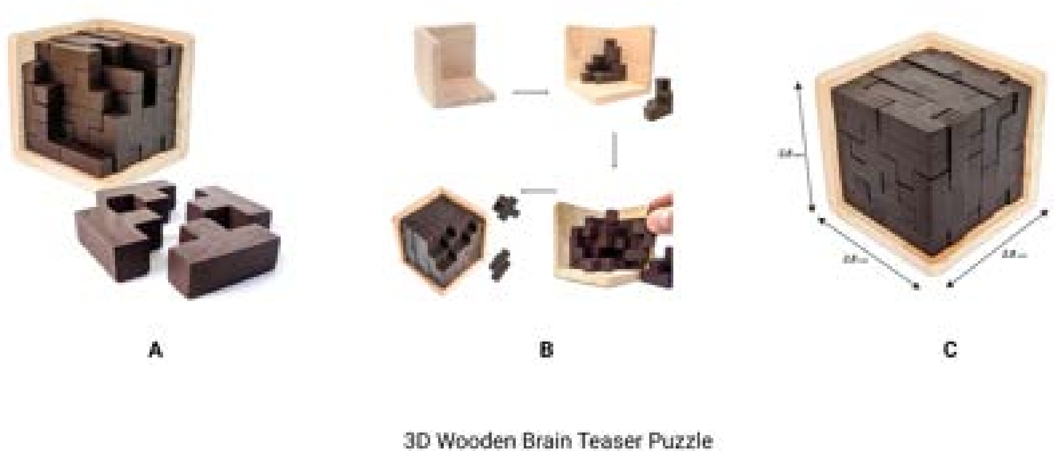

Figure 3.2: **3D Wooden Brain Teaser Puzzle** could be played by kids and adults and helps develop spatial thinking skills. The puzzle is difficult to explain to others if the person has understood how to solve it. One must take out all the wooden pieces and then put them back in a format. In this game, once the user understands the tricks, it is easier to solve. We wanted to capture how the person would explain the tricks she has learned to others. **We discarded this activity** due to the time crunch in ordering the kit. We may use it in future studies. Image of 3D Wooden Brain Teaser Puzzle has been utilised from [63].

A Hungarian architecture professor, Ernõ Rubik, invented the Rubik's Cube in 1974. 3x3 Rubik's Cube is a colour-matching puzzle that allows learning in three-dimensional spaces, see Fig. 3.3. It acts as a brain teaser having six different sides, each composed of nine colourful squares. "*There are 43,252,003,274,489,856,000 ways of arranging the squares, and only one of these is the solution*" [64]. Through turning and twisting, one can put all the colours on the respective side. This forms an exciting proposition to capture how an expert explains to a non-expert to solve the Rubik's cube. Also it would be interesting to capture how hands and eyes coordinate in the process of learning to solve Rubik's cube. We discarded this activity for the current user study as we discovered the Lego car robot for the study. The Lego car robot is modular, so we decided to use Lego instead of Rubik's cube after discussing it with the industry expert.

Figure 3.3: **Rubik's Cube 3x3**: 3x3 Rubik's Cube is a colour-matching puzzle that allows learning in 3-dimensional spaces. It acts as a brain teaser having six different sides, each composed of nine colourful squares. Through turning and twisting, one can put all the colours on the respective side. This forms an exciting proposition to capture how an expert explains to a non-expert to solve the Rubik's cube. **We discarded this activity** for the current user study as we discovered the Lego car robot better for the study. The Lego car robot is modular, so we decided to use Lego instead of Rubik's cube after discussing it with the industry expert. Image of Rubik Cube has been utilised from [65].

The Lego robot car is manufactured by Lego as part of the LEGO MINDSTORMS Education EV3 set, see Fig. 3.4. It has a programmable brick that allows to control of motors and collects sensor feedback and enables to run the robot. The set includes various elements such as structural, connector, and movement that can be used to build a form. Hence it is modular and different elements could be opened up and re-joined. We used this activity after discussing it with the field experts and industry experts. The Lego Robot car allows capturing how user assembles the different parts and how the form is broken up.

Another activity we decided was lockpicking for padlock. The reason to select this was due to the need of the muscle and auditory senses for this activity to accomplish, see in Fig. 3.5.

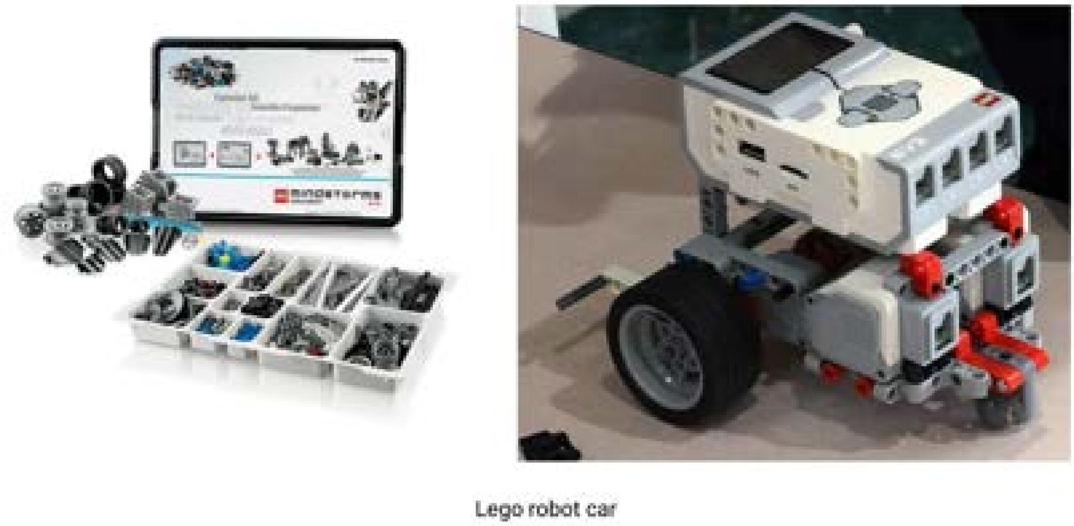

Figure 3.4: **Lego Robot Car** is manufactured by Lego as part of the LEGO MINDSTORMS Education EV3 set. The set includes various elements such as structure, connector, and movement that can be used to build a form. Hence it is modular and different elements could be opened up and re-joined. **We used this activity** after discussing it with the field experts and industry experts. The Lego Robot car allows capturing how the user assembles the different parts and how the form is broken up. Image of Lego Robot Car has been utilised from [66].

Figure 3.5: **Padlock**, being mechanical in nature needs muscle and auditory senses to operate lockpicking. Fig. 3.5 (A) Image of Padlock with cover and without cover has been utilised from [67]. Fig. 3.5 (B) Image of Padlock trying to unlock has been utilised from [68].

3.1.2 Deciding apparatus

We have locked which activities we will do, and now we will check which apparatus would be better for the user study.

We also learned that we should not use screen-based eye tracking. We first conducted the pilot study with the Tobii 5 eye-tracker, which is screen-based see Fig. 3.6(A). It limits the users' movement to the area only covered by the tracker. The device can be mounted anywhere on the monitor, its camera facing the user, and it has a sampling rate of 133 Hz and infrared sensors. The reason to use screen-based was to track the users' heads, hands, and eyes. We discarded to tracking of the heads and prioritise the hands of the users.

Then we tried Pupil Labs Invisible Glasses, a mobile eye tracker that captures unrestricted gaze data, see Fig. 3.6 (B). The eye tracker is mounted on the eye like ordinary eyeglasses. Then we tried Pupil Labs Invisible Glasses, a mobile eye tracker that captures unrestricted gaze data. The eye tracker is mounted on the eye like normal eyeglasses and has a sampling rate of 120 – 200 Hz. The data collection of the hand movements was possible through the Glasses freely. However, we faced limitations in analysing the gaze data on the Pupil Labs software. There was a limitation in analysing the data in terms of metrics. We wanted to use fixation, fixation duration, and saccade to differentiate experts and non-experts, but it was inconceivable. Lastly, we did not have the prescription lens kit of Pupil Labs which limited the recruitment criteria to normal-visioned users.

We used Tobii Pro Glasses 2, which covered all the limitations mentioned above, see Fig. 3.7 (A). The metrics evaluation criteria were possible in the Tobii Pro Glasses software, and we got the prescription lenses that broadened the recruitment criteria. (more details about the eye tracker has been discussed in Section 3.2.2. We decided to use Empatica E4 for collecting the physiological data, see Fig. 3.7 (B).

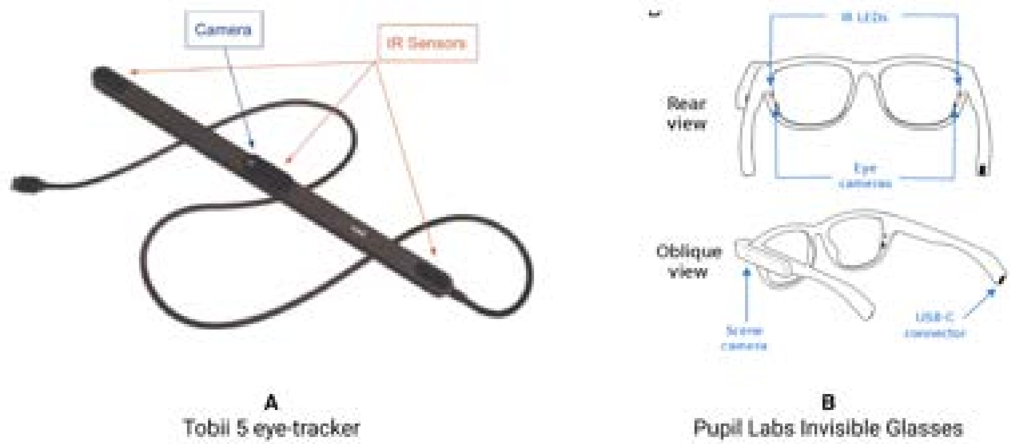

Figure 3.6: Following eye-trackers were used in the pilot studies Fig. 3.6 (A) **Tobii 5 eye-tracker**: screen-based that tracks both head and eye movement. Image of Tobii 5 eye tracker has been utilised from [69]. Fig. 3.6 (B) **Pupil Labs Invisible Glasses**: head-mounted eye trackers that capture gaze data in an unrestrained environment. Image of Pupil Labs Invisible Glasses has been utilised from [70]. We **discarded** these two pieces of equipment.

Figure 3.7: Finalised two pieces of equipment for the user study. **Tobii Pro Glasses 2** and Empatica E4 for physiological data. Fig. 3.7 (A) Tobii Pro Glasses 2: mobile eye tracker. Image of Tobii Pro Glasses 2 has been utilised from [71]. Fig. 3.7 (B) **Empatica E4 wristband**: helps to capture physiological data. Image of Empatica E4 wristband has been utilised from [72]

3.2 Preparatory Phase

The activities were lock-picking and Lego Mindstorm EV3. We decided to pick lock picking as it is mechanical in nature. Lego Mindstorm is about assembling different pieces to make an object. See the activities in the Fig. 3.8. In lock-picking, we compared the data of experts and non-experts. Here we used the top-down cognitive process involving intent or expectation to solve the task. Theoretically, eye movements happen voluntarily, which could help us to understand users' higher-level cognitive functions.

In Lego Mindstorm EV3 (or Lego robot car), we did not compare data rather we tried to capture from the gaze and physiological data of how the user completes the task of assembling the pieces into something. In the Lego Mindstorm activity, we checked the bottom-up cognitive processes of the user. Here we mapped involuntary attention and eye movements that could, in the future, help to train computational models [73, 74].

A
Lock picking set

B
LEGO car robot - EV3RSTORM

Figure 3.8: We decided to use a **padlock** and a **Lego car robot** for conducting the study. Fig. 3.8 (A) Represent lock picking set. It is a non-destructive method of bypassing a lock without using a key [75]. Lock picking techniques such as single pin picking and raking can be used to accomplish this; nonetheless, each approach has the same purpose—to duplicate the motion of the key. Fig. 3.8 (B) Represents a LEGO car robot - EV3RSTORM. It is built by LEGO® MINDSTORMS® robots. It is modular in nature that enables the opening of each piece of the robot [76].

3.2.1 Apparatus Set-up

The user study was conducted at a designated place in the university campus housing a base for the experiment. The experiment facility consisted of the following apparatus as shown in Table 3.1. A total of six categories apparatus were required and few of these categories could have more gadgets. These categories consisted of mix of software and hardware needed to run the experiment smoothly.

Apparatus	Name
Wearable Eye tracker	Tobii Pro Glasses 2.00
PC (principal component) host	Windows laptop to run eye tracker controller software that helped in controlling the basic operations of Tobii Pro eye trackers.
PC	Another windows laptop showed the lock-picking video to users for learning how to use it.
Peripherals	Rechargeable Li-ion Batteries, cables, Ethernet cables, Calibration cards, Corrective lens
Wristband sensor	Empatica E4 wristband
Mobile phone	For connecting Empatica E4 wristband to software for recording the physiological data.
Activity set	Lock-picking kit with pad lock, Lego robot car

Table 3.1: The experiment facility consisted of the following apparatus mentioned in the table.

3.2.2 Wearable Eye tracker

Unlike screen-based eye trackers, wearable eye trackers are designed to let the user go anywhere wherever they need to go to study. Also, wearable helps to capture natural viewing behaviour that could allow users to see to the laptop screen and to the task given at hand. In the study, users were expected to move their hands without any obstruction while doing the task. The selection of wearable eye trackers has been discussed in Section 3.1. Tobii Pro Glasses 2 Eye tracker helped to capture natural viewing behavior in a real-world environment. It had an unobtrusive design with no side or bottom frames and therefore gave a large field of view [77]. Participants could move their heads freely during studies due to the lightweight of the tracker.

While doing the activity the following considerations were taken care so that the eye tracker was not affected. The activity was conducted in an air-conditioned room that prevented users from sweating, in return preventing sweat accumulation on the wearable eye tracker. As eye tracker was not water resistant, we did not allow the chance of spray or rain. The activity was conducted in a closed room and not in the sunlight. The light source was maintained to be constant all the time.

Specifications: Tobii Pro Glasses 2 camera had specifications consisting of the sampling rate in the range of 50Hz to 100 Hz and the resolution was full HD (1920*1080) [77]. Tobii Pro Glasses 2 consisted of the head unit that is wearable eye-tracking glasses. Recording unit was connected to the head unit, see in Fig. 3.9. It helped to record and store eye-tracking data, sound, and scene camera video on a removable SD card. Then we had a PC host to run the eye tracker controller and lab software. Tobii Pro Glasses Controller, an application designed for connecting to the glasses and performing recordings. Tobii Pro Lab Analyser designed for conducting experimental research with Tobii Pro hardware. It helped to analyse individual recordings and aggregate data for quantitative analysis and visualisation. Calibration cards were used for calibration. Corrective lens for the users who needed it. If someone had prescriptive glasses then we used corrective lenses for these users.

Software set-up: Tobii Controller and Lab Analyser were downloaded onto an ASUS PC running Windows 10 (acted as the PC host) with a 2.80 GHz Intel core 2 Quad processor with 16 GB of RAM on a 15-in. liquid crystal display, 1920 × 1080 pixels. The Tobii Pro Glasses 2 hardware (both head unit and recording unit) was connected through WiFi.

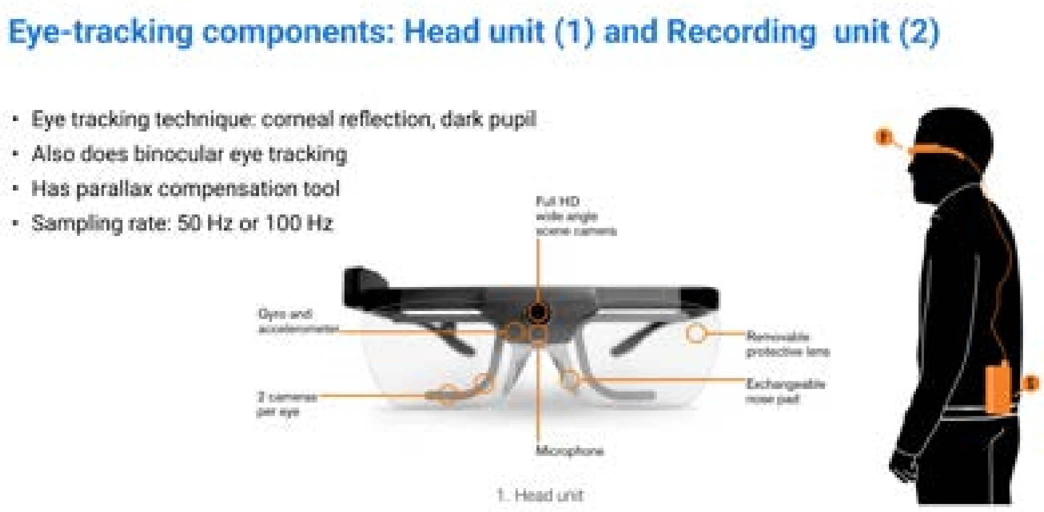

Figure 3.9: Tobii Pro Glasses 2 consisted of the head unit that is wearable eye-tracking glasses and the recording unit connected to the head unit. Image of Tobii Pro Glasses 2 has been utilised from [78].

3.2.3 Empatica E4 Wristband

We used the Empatica E4 wristband device to collect the physiological data to measure heart rate, temperature, acceleration, and skin conductance, see Fig. 3.10. Another key component is that the Empatica E4 is a single device capturing a couple of bio-signals The device's handy watch-like design and cloud access to raw data make it easier to use for the study. It could measure the acceleration data, as well as other physiological parameters, namely the Blood Volume Pulse (BVP), from which the Heart Rate Variability (HRV) and the Inter Beat Interval (IBI) are derived as well skin temperature (SKT) and also changes in certain electrical properties of the skin such as the Electrodermal Activity (EDA) [79].

E4 set-up: The E4 was connected to a android application in real time that streams the visualised activity data coming from the wristband. The E4 was connected to a android application in real time that streams the visualised activity data coming from the wristband.

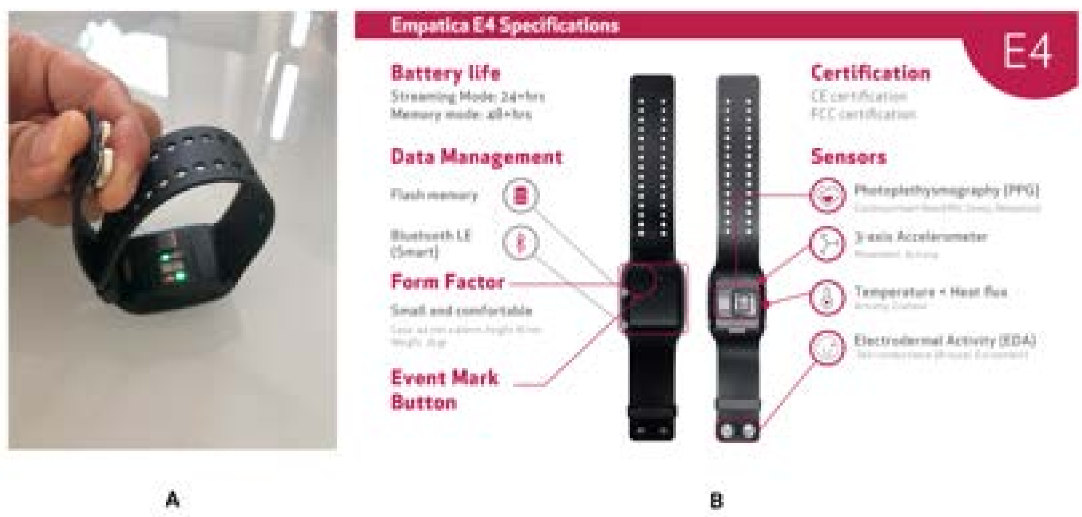

Figure 3.10: Empatica E4 wristband and its specification. Image of E4, Fig. 3.10 (A) has been utilised from [80]. Image of Empatica E4 Specification, Fig. 3.10 (B) has been utilised from [81].

3.3 Design Phase

Participants were recruited through snowball sampling method [82]. We asked contacts and networks to promote sign-up for the study. The targeted population included a selection of male and female novice individuals interested in lock-picking and Lego. We chose a within-subject design where each user was exposed to all conditions and measured how their behaviour changed when the different tasks were changed.

People above the age of 18 who can read, write, listen to the English language, and perform activities with their hands were included in the study. People with glasses with more than one power, i.e., bifocals, trifocals, and progressives (e.g., Varilux), were removed. People who had eye surgery, such as corneal (e.g., LASIK), cataract, and intraocular implants, were also removed. People with eye movement or alignment abnormalities, such as lazy eyes, were also removed. We did over recruitment to get an old age person as well into the study.

The following considerations were taken care of before starting the experiment. Participants were asked to wear minimal eye makeup while coming for the experiment. They were asked to bring or wear corrective optics, such as single-vision glasses or contact lenses, in need base cases. The cleanliness of the participants' corrective eyewear was checked.

Before starting user study: We developed a one-sheet document to introduce our study to the participants, check in Appendix A. When participants arrived, we verbally introduced the study and the ground rules that helped to take care of the above-mentioned considerations. The document consisted of the study brief, expectations from them and the benefit of participating in the study. Participants were introduced to eye tracking and physiological data. We explained in general terms how eye tracker and wristband sensor work. Then a consent form was given to the participants to sign before initiating the next steps, check in Appendix B. In the form, we took their permiss n to use the data from the research perspective for future research and modelling the outcome. Once we had provided a study overview, participants reviewed expectations and provided an introduction to eye tracking and wristband sensor, signed the consent form, participants were allowed to ask anything related to the study if they had questions. If they asked, we provided clear information before transitioning to calibration (more details in **??**). We maintained a comfortable experiment scenario so that the participant felt relaxed. For this, the moderator was asked to keep their tone light and friendly and avoid overly technical explanations.

The table showcase the total number of participants recruited for the study. Out of 21 participants, the study proceeded fluently with 11 participants (Four females, and Eight males) fulfilling all the considerations, see in Table 3.2. Every participant was asked to wear Empatica E4 and Tobii Pro Glasses 2 during the study.

Participant	Age	Gender	Used Lockpicking tool	Played with Lego
P01	18 - 25	Male	No	Yes
P02	18 - 25	Male	Yes	Yes
P03	18 - 25	Female	No	No
P04	40 - 47	Male	Yes	Yes
P05	47 - 60	Male	No	Yes
P06	25 - 33	Male	No	No
P07	18 - 25	Female	No	No
P08	25 - 33	Male	No	Yes
P09	25 - 33	Female	No	Yes
P10	25 - 33	Male	No	Yes
P11	25 - 33	Female	No	No

Table 3.2: Participant table: A list of participants who were involved in the user study. Through these participants, we studied the difference between gaze movements and physiological data while doing the tasks.

3.4 Data Collection Phase

The following steps were taken before starting the experiments. The eye tracker was prepared by charging the battery, inserting the SD memory card and a battery in the recording unit, attaching the nose pad if needed, installing Tobii Pro software, and connecting all the cables. Empatica E4 sensor was prepared by charging the wristband and connecting it with an android phone application. Windows laptops and an android smartphone were charged.

Before commencing the experiments, a fifteen-minute brief was provided to the participant, highlighting the tasks to be completed and an overview of necessary knowledge of lock-picking and the Lego robot car. This is followed by an explanation of eye tracking in the study and what information would be collected.

All participants were asked to wear an Empatica E4 wristband on their right-hand irrespective of their dominant hand, gender, and age. Then an eye tracker was given to them to wear on their eyes. Then they performed the activities. Before collecting the data, the eye tracker and wristband sensor were calibrated and validated.

Calibration: Calibration is necessary to achieve good accuracy [1] and precision [2]. This is another consideration that was taken to get consistent accurate gaze and physiological data. The participants were asked to wear the head unit and focus their gaze on the

[1]Accuracy means the difference between the expected and actual gaze position [**?**].
[2]Precision is the scatter in multiple gaze points directed at a target [**?**].

centre of the calibration card. The calibration was done for each user individually. The distance between the participant and the calibration card was maintained at one meter from the eye tracker. Participants were asked to hold the calibration card at arm's length for approximately the correct distance. The card was held still during the calibration process. Then participants fixated their gaze on the centre of the target.

The effectiveness of the physiological data was tested by hand movement was tested. A short test was performed with a comfortable tightness of the device on the wrist. The participant was asked to bang on the table by the hand she was wearing the Empatica E4.

Validation: This step was followed immediately after calibration. This step was intended to show how an individual would be tracked. Validation helps visually to determine how closely the calibrated eye model maps gaze points to the target of looking. In the eye tracker, validation used the 3D eye model, which is used to calculate the participant's actual performance. Participants were asked to look at the calibration card, i.e., focus right on the target's centre point, and then assess how close the actual gaze points were and the degree of scattering. If the validation was inaccurate, meaning the placement of the fixation over the target was not correct, then the target was refitted, and the participant was asked to repeat the calibration process.

Once the calibration was validated for the eye tracker and wristband, the recording was started through Tobii Pro Controller software. The software gave access to the live view functionality of the users' view and the audio recorded through the Tobii Pro Glasses 2 head unit. After experiments were finished, the recording was stopped through the controller software. The recorded session was available for playback through the Tobii Pro Lab analyser and for analysing. The data was downloaded for each participant and kept in the university's laptop folder.

Activities description: The first activity was about lockpicking that has two subparts. In the first part, padlock with cover for lockpicking and second part, padlock without cover for lockpicking, see Fig. 3.11. The participants were shown a video of four minutes to get the understanding of how lockpicking has to be done. And then the third activity was on assembling and dissembling Lego robot car. The user were asked to remove tyre and then put it back, see Fig. 3.12.

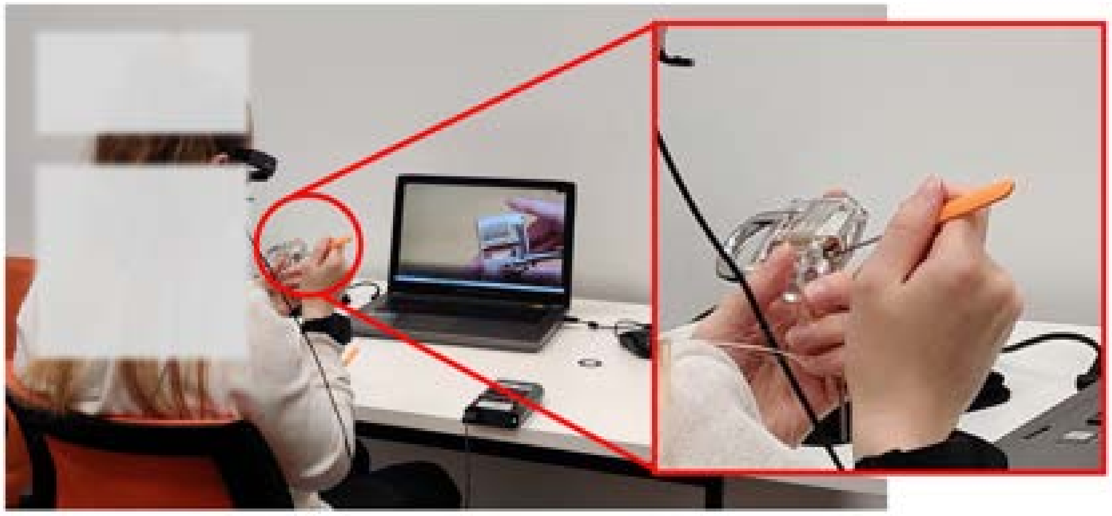

Figure 3.11: A participant using doing task 2 is lockpicking without cover on the padlock.

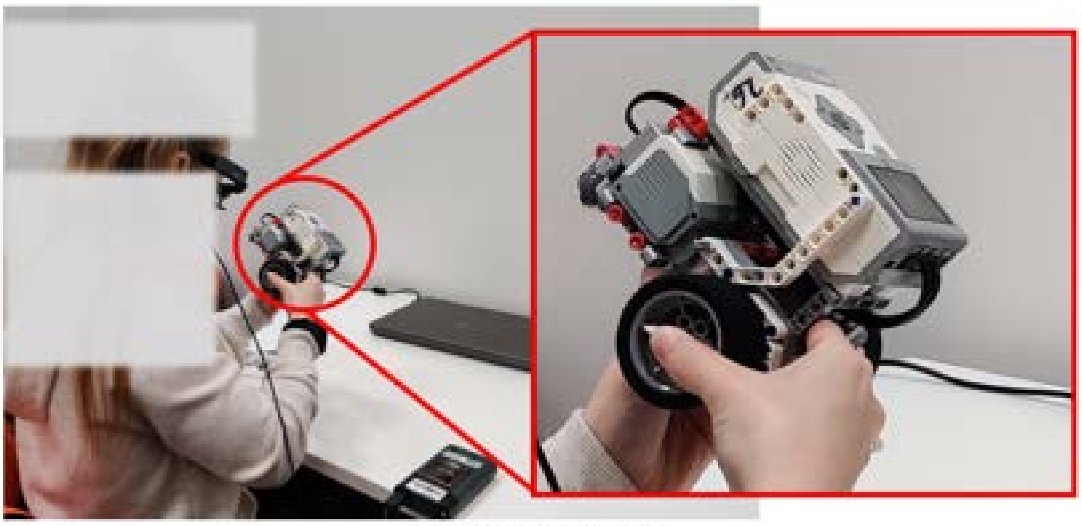

Figure 3.12: A participant using doing task 3, i.e., assembling and disassembling Lego robot car

And in both activities users' gaze and physiological data was tracked. Activities conduted in the user study have been written in this Table 3.3

Activities	Details
Activity 1	Lockpicking with cover on pad lock
Activity 2	Lockpicking without cover on pad lock
Activity 3	Disassembling and assembling Lego robot car

Table 3.3: The table highlights the activities conducted in the user study. There were three studies that were designed after doing the pilot studies.

In Fig. 3.13, participants were asked to wear an eye tracker and a physiological wristband to capture gaze moments and heart rate data. Two laptops were used in the study. One laptop helped control the eye tracker, and a smartphone recorded physiological wristband data. Another laptop was used to showcase the video to the participant. Fig. 3.14 showcased three activities conducted in the user study to differentiate experts and non-experts and check whether the method would be fruitful in capturing tacit knowledge or not.

Figure 3.13: Participants were asked to wear an eye tracker and a physiological wristband to capture gaze moments and heart rate data. Two laptops were used in the study. One laptop helped control the eye tracker and a smartphone recorded physiological data from wristbands. Another laptop was used to showcase the video to the participant. Fig. 3.13 (A) An expert participant trying to complete the task to unlock pad lock Fig. 3.13 (B) A non-expert participant trying to first learn how to unlock a pad lock through video.

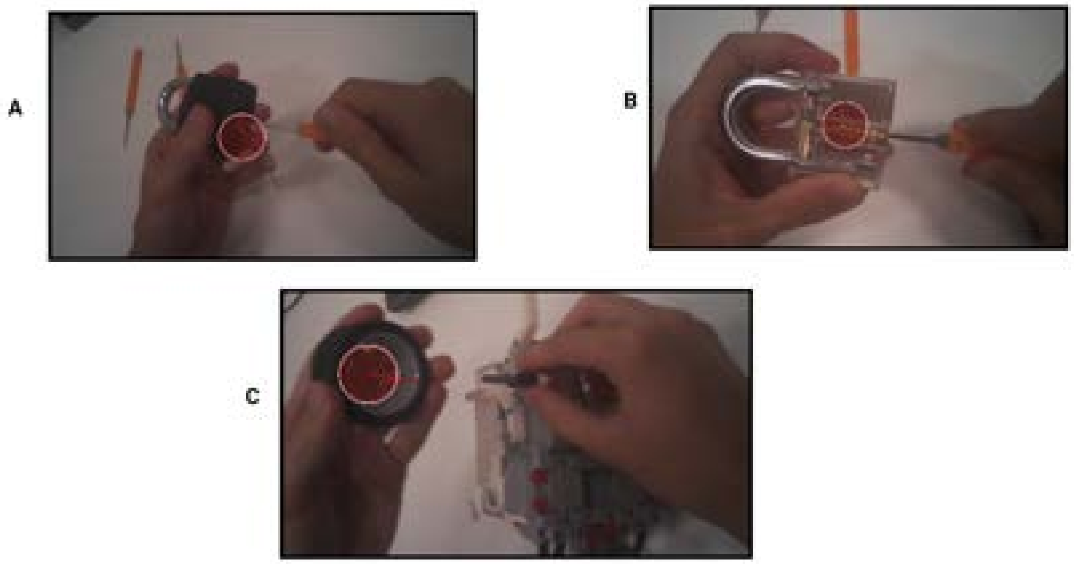

Figure 3.14: Three photos showcased three activities conducted in the user study to differentiate experts and non-experts and check whether the method would be fruitful in capturing tacit knowledge or not.

Chapter 4

Findings

We have shown till now how the study was conducted in a controlled environment. We would move now to understand what data was collected and what we could infer from it. There was one expert (P02) in lockpicking in our study, and we compared the rest of the users' gaze data with them. As per the hypothesis, experts formulate the next step while doing the task as they are aware of the situation. This was seen in the case of P02, where eyes were looking somewhere else while doing the lockpicking of the padlock. In comparison, the rest of the users were focusing on the padlock the whole time during the task.

The heart rate and skin conductance data collected from Empatica E4 were discarded as we could not correlate the physiological data with the gaze data. As we used two different apparatuses for collecting the data, there was a mismatch in the scale on which data was produced. On another occasion, the accelerometer data was normal, and there were no fluctuations in the data, even if the hands were moving. This might have happened due to calibration and a mismatch of the frequency in which it is captured. We might analyse the data again in the future study collected by the Empatica E4, but for this analysis, we would not be presenting the physiological data. Below, the analysis is based on the gaze data.

Eye tracking measurements:

The data set achieved from the 11 participants included a total of 1015 minutes of recorded eye data. Before analysing the data, we made sure the data was preserved and that the quality of the data was good to proceed. For analysing the video data we used Tobii Pro Lab software [77] and excel sheets to visualise and do comparisons between users' eye tracking data.

Here are the measurements that we used for the analysis:

- Gaze samples represent the percentage of gaze samples of sufficient quality to process for analysis. It includes all the samples from the calibration until the recording stops, providing a rough estimate of the quality of the complete recording.
- Fixation is the period where the eyes are relatively still, taking in detailed information about what is being looked at.
- Saccades are eye movements which occur when the eyes move quickly between fixations. Saccades occur when the eyes move quickly between fixations, when the eyes are relatively still, taking in information from what we are looking at.
- Saccadic motion consists of a sequence combination of saccades and fixations, one followed by the other.
- In an eye tracking heatmap, a heatmap is plotted from the data collected by tracking the movement of a user's eyeballs at an individual element as well as the fixation length on that individual element. It help to see the gaze plots which highlight the order and location of fixations during an eye tracking task.

4.1 Task 1: Lockpicking with cover

In task 1 and task 2, we wanted to capture the top-down approach of the users where the users is required to use their previous similar mental model to solve the task [83]. Also, we provided the users a set of instructions to solve the tasks. Here the role of observation is important to fulfil the goal of the task. The visual attention moves as per the information understood by the user. As there are many minute objects in the locking to check, it is difficult to see the speed of the saccade, but through mathematically it is possible to check.

The following shows Table 4.1, average fixation count and fixation count. The expert in the case was found to have more average fixation duration and less fixation count. The expert is P02. Less fixation count means that the user already knows what she is using and possibly making the next steps prediction. It is also possible that the user is receiving sensory data that might be helping her to understand and take the following steps. Fixation duration is more for the expert as she is in the attentive stage and has more focus on the task. This means the eye movements are not moving randomly, but there is a meaning in the movement. This movement could mean the potential use of the existing mental model, but we are not sure about this.

TASK1: Lock Gaze With Cover		
Participant	**Avg Fixation duration**	**Fixation count**
P01	0.42	356
P02	0.64	27
P03	0.31	792
P04	0.41	38
P05	0.41	93

Table 4.1: Highlights the average fixation duration of eleven participants. P02 has the highest average fixation duration

Expert, P02 is show cased in Fig. 4.1. We compared expert data with the rest non-expert users. Visualisation of the task done by non expert, P02 in Fig. 4.2 and non expert, P05, in Fig. 4.3

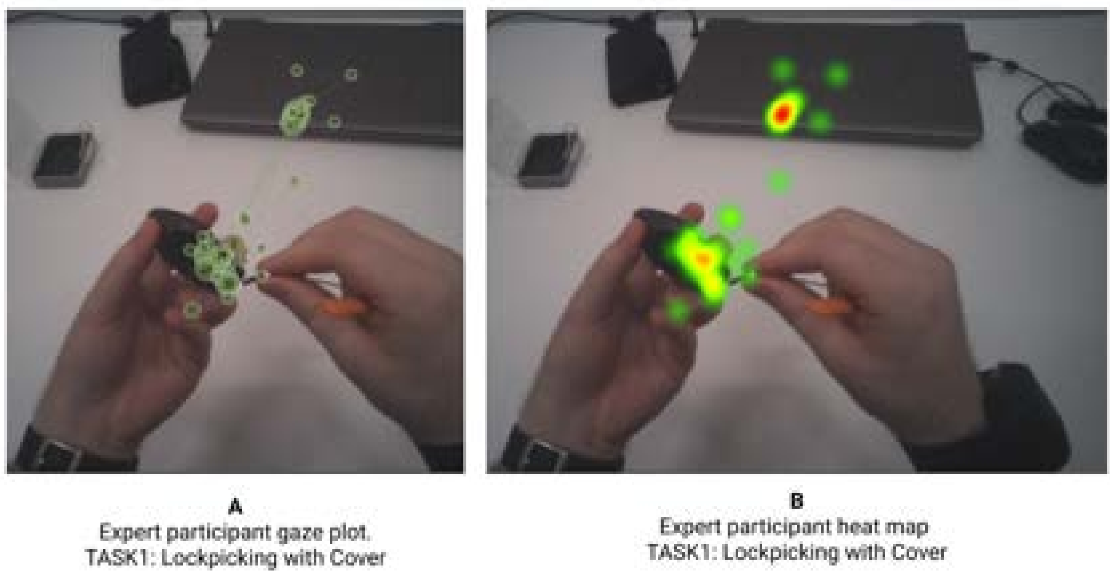

Figure 4.1: TASK1: Lockpicking with Cover. Fig. 4.1 (A) Participant P02 gaze plot. In this image, we are able to see the gaze plot that tells us the participant's eye path. Lockpicking is the task at hand where the participant is looking but she is also looking at another item as well. Fig. 4.1 (B) Participant P02 heat map. The heat map is plotted from the gaze data as well as from the fixation length of P02. Hence we could see the most and least attention sections.

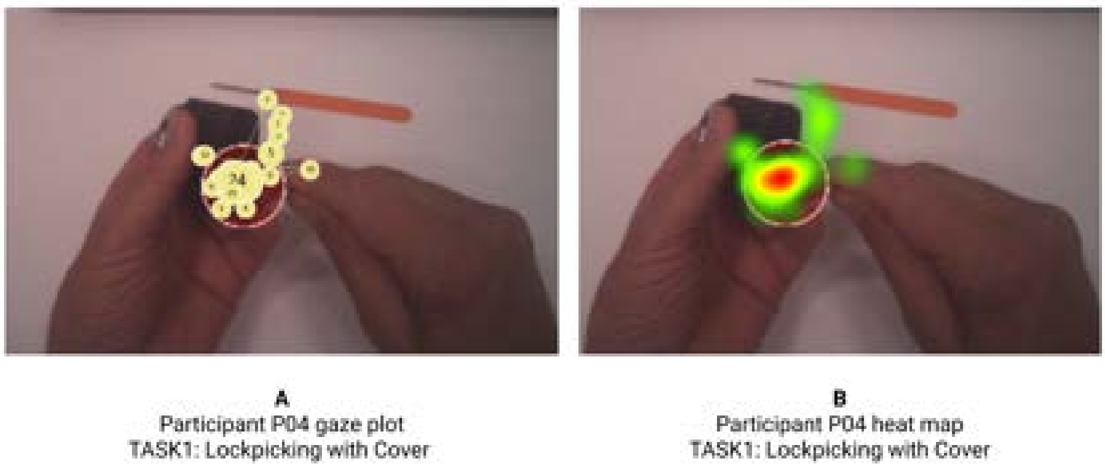

Figure 4.2: TASK1: Lockpicking without cover of non expert P04. Fig. 4.2 (A) Gaze Plot. Fig. 4.2 (B) Heat Map.

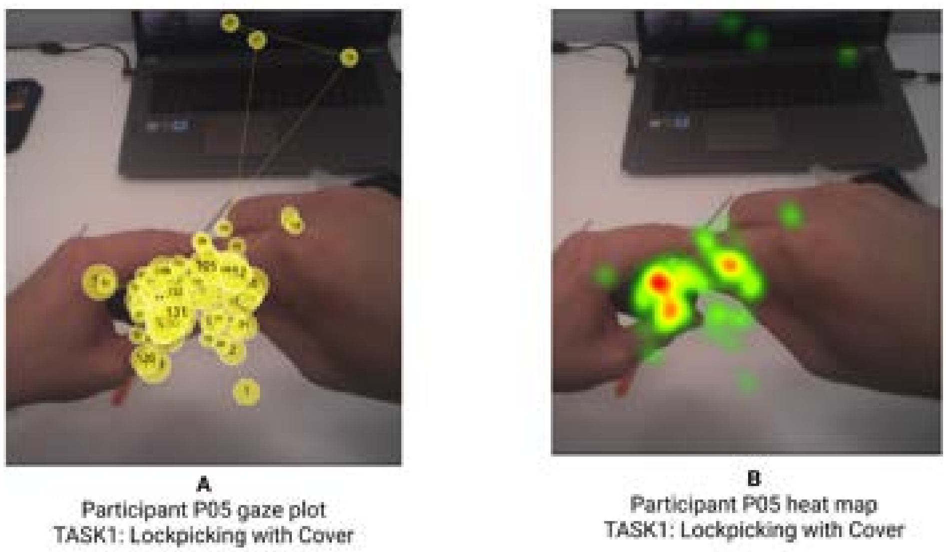

Figure 4.3: TASK1: Lockpicking without cover of non expert P05. Fig. 4.3 (A) Gaze Plot. Fig. 4.3 (B) Heat Map.

4.2 Task 2: Lockpicking without cover

Expert, P02 is show cased in Fig. 4.4. We compared expert data with the rest non-expert users. Visualisation of the task done by non expert, P09 in Fig. 4.5 and non expert, P11, in **??**. After doing the lockpicking on padlock, we asked the users to remove the cover from the pad lock. This enabled the users to see the inner workings of the padlock such as springs, torsion.

We found that every user curiously looked at the inner functioning of the padlock and even the expert. We got from the users why they are not looking elsewhere else because the springs got their attention. Also, the video shown to them mentioned the functioning of the padlock, so they were relating what was told in the video and what was there in hand.

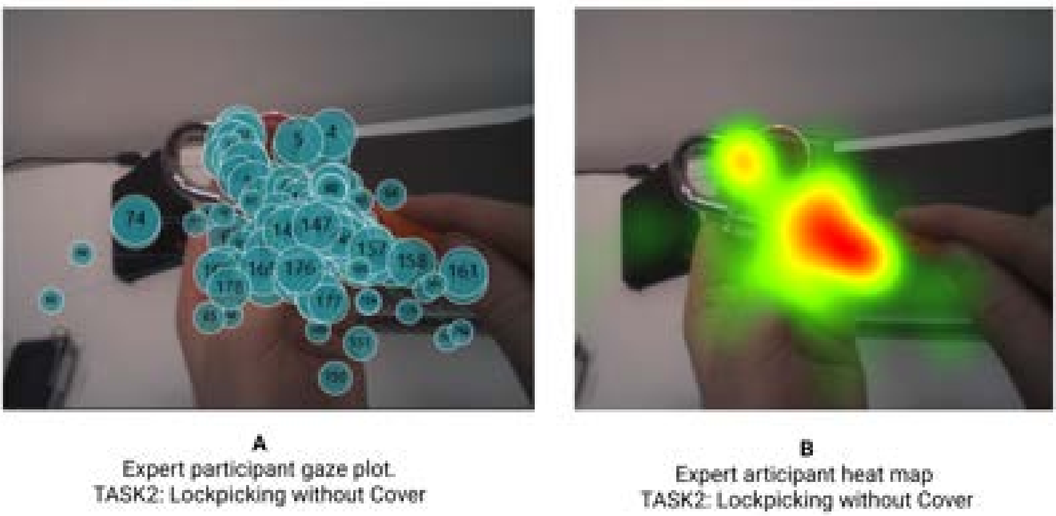

Figure 4.4: TASK2: Lockpicking without cover of expert P02. Fig. 4.4 (A) Gaze Plot. Fig. 4.4 (B) Heat Map.

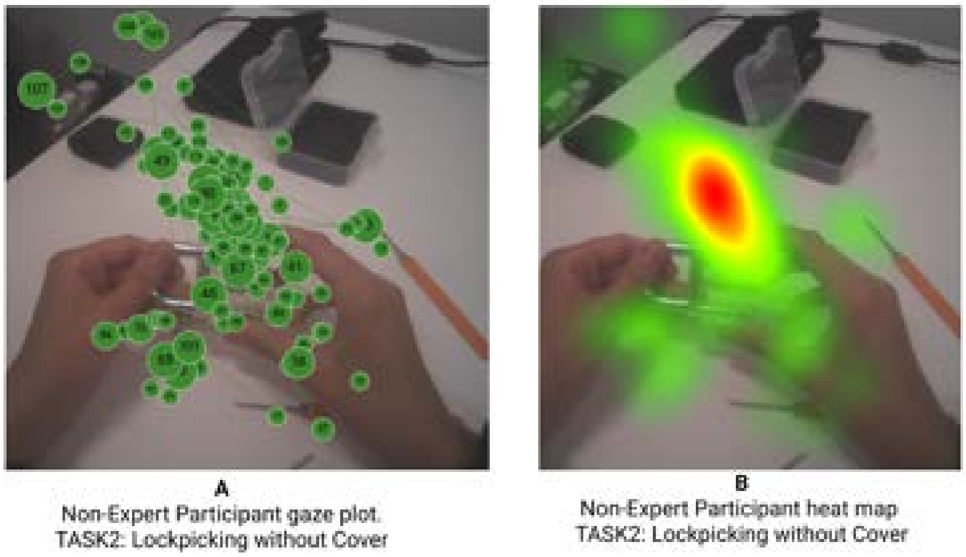

Figure 4.5: TASK2: Lockpicking without cover of non expert P09. Fig. 4.5 (A) Gaze Plot. Fig. 4.5 (B) Heat Map.

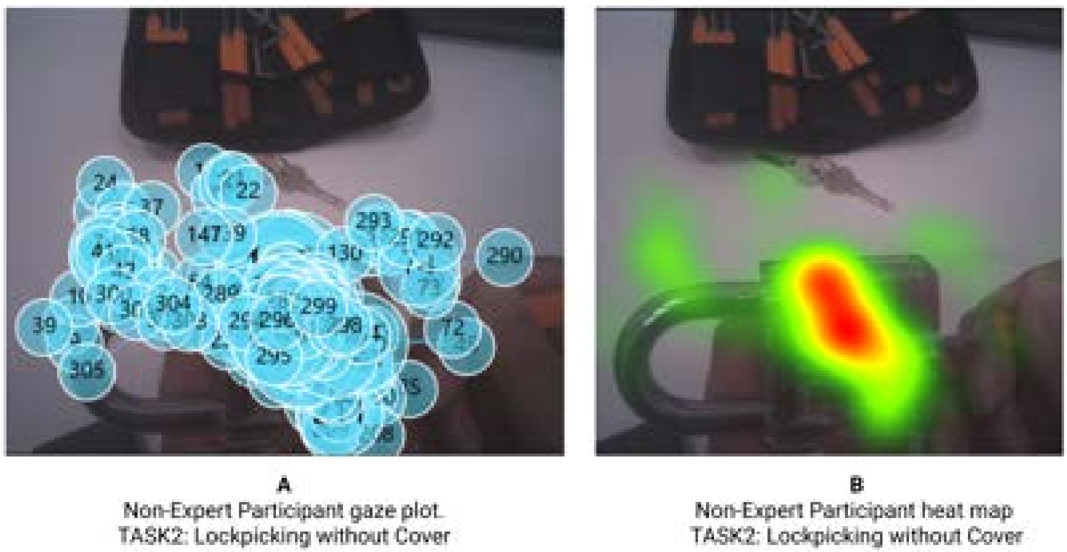

Figure 4.6: TASK2: Lockpicking without cover of non expert P11. Fig. 4.6 (A) Gaze Plot. Fig. 4.6 (B) Heat Map.

4.3 Task 3: Lego robot car

The users were asked to remove the tyres and assemble them back on the lego. Here it is difficult to analyse the data as there is no difference in the fixation and saccade from the gaze plot and heat. Through this activity, we aim to capture the bottom-up mechanisms of visual attention [83]. Here we wanted to capture users abstraction of the information when no information is provided to them.

Expert, P02 is show cased in Fig. 4.7. We compared expert data with the rest non-expert users. Visualisation of the task done by non expert, P01 in Fig. 4.8 and non expert, P03, in Fig. 4.9 are illustrated with gaze plot and heat map respectively. As per theory, the gaze moments are fast in bottom up attention but it is difficult to analyse from the current visualisations.

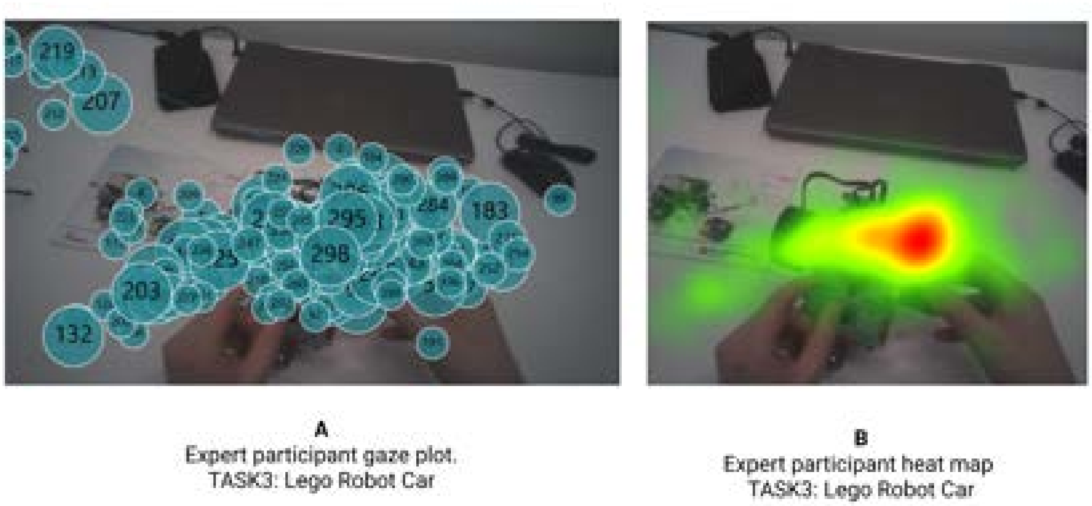

Figure 4.7: TASK3: Assembling and Disassembling of Lego Robot Car by the expert P02. Fig. 4.7 (A) Gaze plot. Fig. 4.7 (B) Heat Map.

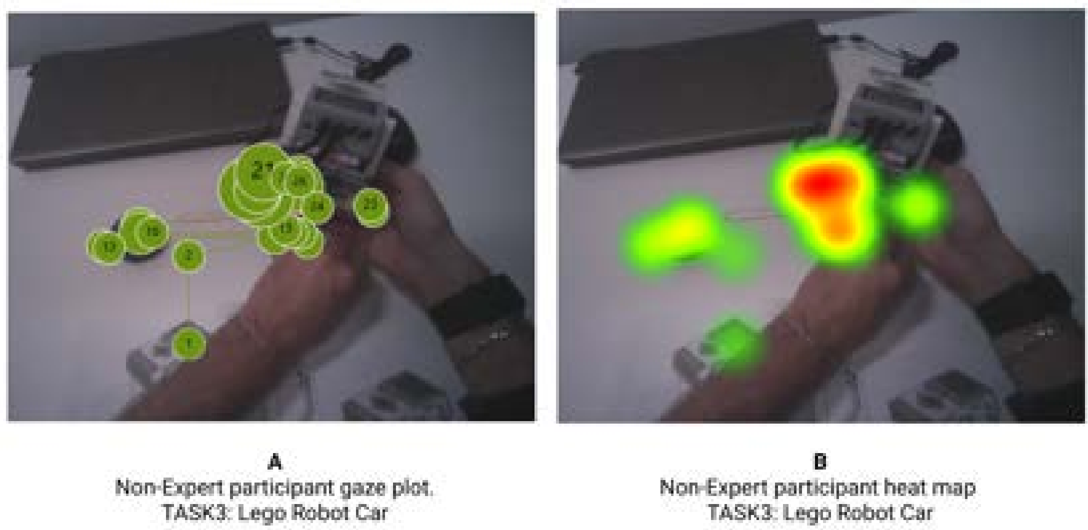

Figure 4.8: TASK3: Assembling and Disassembling of Lego Robot Car by non-expert P01. Fig. 4.8 (A) Gaze Plot Fig. 4.8 (B) Heat Map.

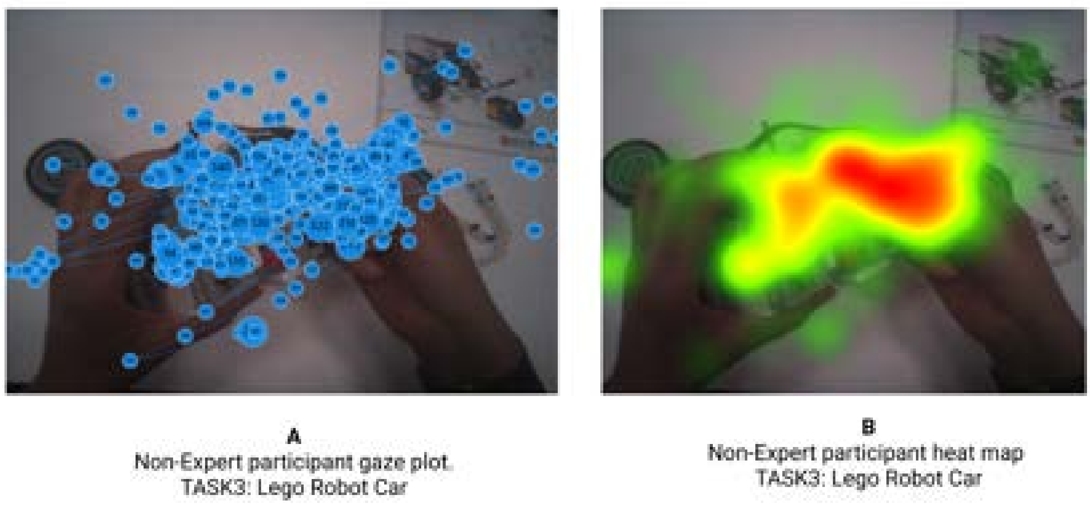

Figure 4.9: TASK3: Assembling and Disassembling of Lego Robot Car by non expert P03. Fig. 4.9 (A) Gaze Plot Fig. 4.9 (B) Heat Map

Chapter 5

Discussion

As we intend to capture tacit knowledge from the experts and transfer it to non-experts through the use of intelligent machines, we should look at how we would design such intelligent machines. Our findings helped us to understand what constitutes an expert and a non-expert. Now we shall reflect upon how should the design and development of the machines should be in center to support and transfer tacit knowledge in humans.

Situating our findings Chapter 4 and related work 2 in the context of an industrial setting where a technician carries their tool and equipment onto the field. We should be conscious about how we design a machine that captures their work and workflow at the same time and helps improve their work by sharing their surrounding peers' experiences and tacit knowledge. When we talk about work and workflow, we are particularly interested in tacit knowledge that is dependent on the technicians' work environment and how feedback from that environment affects their work.

Before moving forward, we would like to bring in the discussion of the knowledge workers and the similarities to that of the industrial technicians. Peter Drucker, coined the word 'knowledge worker" in 1973 [84]. He described this word in the context of the growing number of employees in business organisations. "The manual worker is yesterday...The basic capital resource, the fundamental investment, but also the cost centre for a developed economy is the knowledge worker who puts to work what he has learned in systematic education, that is, concepts, ideas, and theories, rather than the man who puts to work manual skill or muscle." [84]. As per Cambridge dictionary, a technician is defined as - "a worker trained with special skills or knowledge, esp. in how to operate machines or equipment used in science." or "someone whose job is to make sure that machines and equipment work correctly, and to repair them if necessary." [85].

Alison Kidd in 1994 mentioned that knowledge workers solve problems not by looking at the rules and procedures given to them but rather use internal knowledge that they have developed over time [86]. Workers develop their own processes toward the problem and it is affected by their thinking and the situations they are in. This process is stored in the heads of knowledge workers and it is spatial and temporal in nature. The objects they interact with have a spatial relationship that helps in creating, exploring, and changing the form which is novel and constitutes new knowledge. For example, let's take the role of a sticking note in the daily life of a knowledge worker. A piece of information written on a sticky note helps the worker to remind a thought related to the specific work. That piece of information may be discarded once the work has been finished. The same is the criteria with tacit knowledge, the thought at a particular space and time is useful for an instance. Once it has been put in place then it is gone.

Potential research question to explore: How to design an intelligent machine that would focus on supporting the act of informing humans rather than storing or processing information on humans' behalf? We want to develop a machine that helps workers in the organisation to be informed about their environment and act more efficiently concerning the environment by providing cues or hints towards tacit knowledge.

Not all knowledge can be tacit:

The information that needs to be memorised and retrieved is not tacit. Suppose it does not need to be internalised, such as a contact list, periodic chemical table, meetings, passwords, and driving license number. In that case, it can be stored in external memory that humans could refer to whenever needed. Current machines act as a tool for storing and retrieving information and do not help build a piece of knowledge. Knowledge formation happens over time through thinking and connecting the pieces of information.

We consider the human brain to work the same as Von Neumann's computer architecture, but that is not true. Von Neumann has been used in understanding human knowledge for more two-three decades, where we equate knowledge to retrieving data from a passive store to inform action [87]. Instead humans have powerful information processors that continuously change the perception of objects and the environment in which they live.

A way forward:

We want to create an artefact that could create a meaningful feedback loop. Consider the kitchen of a chef. There are all the things to cook, and the chef knows exactly what to do, but they do not store that in their head the same way. Instead, they know their hands. Hence their chief knowledge is contextual and situated in the environment where they work. Taking inspiration from the chef's kitchen, we want o to develop and embody technology that supports and sustains, enhances, and transforms skilled interactions of the technician in their tools, meaning making the technology socially situated practice. Not just a tool to complete the task, but that reminded the technician of ways to improve and reflect on their knowledge.

Here we do not mean to develop another Fitbit product that is just on the body, but a technology supporting interactions that acknowledge situated practices. A technology that helps create and develop their skills in social interaction with other people.

Chapter 6

Conclusions

We demonstrated the difference between expert and non-expert based on the gaze data. The empirical result from the study co-relates with the theory. This gives us the future direction for the research to explore further the use of physiological data to find key moments that are nothing but tacit knowledge. We will design a separate control group in the future of the experts and then compare their results with non-experts.

We faced quite a few limitations during this research project. Those were especially related to the use of software and hardware. Calibration and validation could make a lot of difference. If we want to capture two different sensory data, then it would be better to use the hardware manufactured by the same company. Visualisation of the data is another, as data gets corrupted when exported from the software.

Bibliography

[1] T. H. Davenport, L. Prusak *et al.*, *Working knowledge: How organizations manage what they know*. Harvard Business Press, 1998.

[2] M. Hudecheck, C. Sirén, D. Grichnik, and J. Wincent, "How companies can respond to the coronavirus." *MIT Sloan Management Review*, 2020.

[3] H. A. Nold, "Making knowledge management work: tactical to practical," *Knowledge Management Research & Practice*, vol. 9, no. 1, pp. 84–94, 2011.

[4] L. Cardoso, A. Meireles, and C. F. Peralta, "Knowledge management and its critical factors in social economy organizations," *Journal of knowledge management*, 2012.

[5] M. Polanyi, "The tacit dimension," in *Knowledge in organizations*. Routledge, 2009, pp. 135–146.

[6] R. Stata, "Organizational learning-the key to management innovation," *MIT Sloan Management Review*, vol. 30, no. 3, p. 63, 1989.

[7] J.-H. Woo, M. J. Clayton, R. E. Johnson, B. E. Flores, and C. Ellis, "Dynamic knowledge map: reusing experts' tacit knowledge in the aec industry," *Automation in construction*, vol. 13, no. 2, pp. 203–207, 2004.

[8] S. Ojha and P. Yammiyavar, "Role of language in transfer of tacit knowledge: Case study of bamboo crafts making industries in northeast india," in *Ergonomics in Caring for People*. Springer, 2018, pp. 337–343.

[9] D. Miller and M.-J. Chen, "Sources and consequences of competitive inertia: A study of the us airline industry," *Administrative science quarterly*, pp. 1–23, 1994.

[10] K. S. B. KALID and A. K. Mahmood, “The use of storytelling in sharing tacit knowledge in government organisations,” *Public sector ICT Management review*, vol. 3, no. 1, 2009.

[11] L. Hou, S. Wu, G. Zhang, Y. Tan, and X. Wang, “Literature review of digital twins applications in construction workforce safety,” *Applied Sciences*, vol. 11, no. 1, p. 339, 2020.

[12] T. Haase, W. Termath, and M. Martsch, “How to save expert knowledge for the organization: methods for collecting and documenting expert knowledge using virtual reality based learning environments,” *Procedia Computer Science*, vol. 25, pp. 236–246, 2013.

[13] A. Kokkas and G.-C. Vosniakos, “An augmented reality approach to factory layout design embedding operation simulation,” *International Journal on Interactive Design and Manufacturing (IJIDeM)*, vol. 13, no. 3, pp. 1061–1071, 2019.

[14] A. Chalmers and A. Ferko, “Levels of realism: From virtual reality to real virtuality,” in *Proceedings of the 24th Spring Conference on Computer Graphics*, 2008, pp. 19–25.

[15] A. Peña-Rios, O. C. Bahceci, V. Gupta, A. Conway, and G. Owusu, “Work-in-progress—a web-based virtual reality training simulator for field service telecommunications engineers,” in *2020 6th International Conference of the Immersive Learning Research Network (iLRN)*. IEEE, 2020, pp. 316–319.

[16] D. Zhao and J. Lucas, “Virtual reality simulation for construction safety promotion,” *International journal of injury control and safety promotion*, vol. 22, no. 1, pp. 57–67, 2015.

[17] DexGreen. (2022) Dexgreen fibre optic demarcation box - dexgreen. [Online]. Available: https://dexgreen.com/products/fiber-optic-demarcation-box

[18] K. Harezlak and P. Kasprowski, “Application of eye tracking in medicine: A survey, research issues and challenges,” *Computerized Medical Imaging and Graphics*, vol. 65, pp. 176–190, 2018.

[19] K. Woodcock, “Model of safety inspection,” *Safety science*, vol. 62, pp. 145–156, 2014.

[20] S. Sadasivan, J. S. Greenstein, A. K. Gramopadhye, and A. T. Duchowski, “Use of eye movements as feedforward training for a synthetic aircraft inspection task,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ser. CHI

'05. New York, NY, USA: Association for Computing Machinery, 2005, p. 141–149. [Online]. Available: https://doi.org/10.1145/1054972.1054993

[21] History of weapons. [Online]. Available: https://en.wikipedia.org/wiki/History_of_weapons

[22] P. M. Fitts, *Human performance*, 1967.

[23] D. Bell, "The coming of the post-industrial society," in *The Educational Forum*, vol. 40, no. 4. Taylor & Francis, 1976, pp. 574–579.

[24] K. Yukawa, "Towards the knowledge creating society through the use of it-community as a new platform," *Economic review*, vol. 7, no. 1, pp. 108–134, 2003.

[25] B. Ancori, A. Bureth, and P. Cohendet, "The economics of knowledge: the debate about codification and tacit knowledge," *Industrial and corporate change*, vol. 9, no. 2, pp. 255–287, 2000.

[26] F. Nickols, "The tacit and explicit nature of knowledge: The knowledge in knowledge management," in *The knowledge management yearbook 2000-2001*. Routledge, 2013, pp. 12–21.

[27] I. Nonaka and H. Takeuchi, "The knowledge-creating company," *Harvard business review*, vol. 85, no. 7/8, p. 162, 2007.

[28] J. R. Anderson, *Cognitive psychology and its implications*. Macmillan, 2005.

[29] M. Polanyi, "Tacit knowing: Its bearing on some problems of philosophy," *Reviews of modern physics*, vol. 34, no. 4, p. 601, 1962.

[30] G. Ryle, "Knowing how and knowing that: The presidential address," in *Proceedings of the Aristotelian society*, vol. 46. JSTOR, 1945, pp. 1–16.

[31] S. Schmidt, M. Limbach, S. Langner, K.-P. Wiedmann, L. Albertsen, and P. Reiter, "Official sports sponsorship fortress vs ambush marketing attack: Investigating the impact on implicit and explicit brand knowledge," *International Journal of Sports Marketing and Sponsorship*, 2018.

[32] T. Haldin-Herrgard, "Difficulties in diffusion of tacit knowledge in organizations," *Journal of Intellectual capital*, vol. 1, no. 4, pp. 357–365, 2000.

[33] V. L. Patel, J. F. Arocha, and D. R. Kaufman, "Expertise and tacit knowledge in medicine," in *Tacit knowledge in professional practice*. Psychology Press, 1999, pp. 89–114.

[34] C. Hummels and J. Van Dijk, "Seven principles to design for embodied sensemaking," in *Proceedings of the ninth international conference on tangible, embedded, and embodied interaction*, 2015, pp. 21–28.

[35] K. Aspegren and P. LØnberg-Madsen, "Which basic communication skills in medicine are learnt spontaneously and which need to be taught and trained?" *Medical teacher*, vol. 27, no. 6, pp. 539–543, 2005.

[36] I. Arikpo, F. Ogban, and I. Eteng, "Von neumann architecture and modern computers," *Global Journal of Mathematical Sciences*, vol. 6, no. 2, pp. 97–103, 2007.

[37] S. Card, T. MORAN, and A. Newell, "The model human processor- an engineering model of human performance," *Handbook of perception and human performance.*, vol. 2, no. 45–1, 1986.

[38] J. Rasmussen, "Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models," *IEEE transactions on systems, man, and cybernetics*, no. 3, pp. 257–266, 1983.

[39] S. E. Dreyfus and H. L. Dreyfus, "A five-stage model of the mental activities involved in directed skill acquisition," California Univ Berkeley Operations Research Center, Tech. Rep., 1980.

[40] T. H. Davenport, D. W. De Long, and M. C. Beers, "Successful knowledge management projects," *MIT Sloan management review*, vol. 39, no. 2, p. 43, 1998.

[41] J. Hayano, H. Yamamoto, I. Nonaka, M. Komazawa, K. Itao, N. Ueda, H. Tanaka, and E. Yuda, "Quantitative detection of sleep apnea with wearable watch device," *PLoS One*, vol. 15, no. 11, p. e0237279, 2020.

[42] F. Delmastro, F. Di Martino, and C. Dolciotti, "Cognitive training and stress detection in mci frail older people through wearable sensors and machine learning," *Ieee Access*, vol. 8, pp. 65 573–65 590, 2020.

[43] F. Sabry, T. Eltaras, W. Labda, K. Alzoubi, and Q. Malluhi, "Machine learning for healthcare wearable devices: The big picture," *Journal of Healthcare Engineering*, vol. 2022, 2022.

[44] H.-Y. Tsai, D. Compeau, and N. Haggerty, "Of races to run and battles to be won: Technical skill updating, stress, and coping of it professionals," *Human Resource Management: Published in Cooperation with the School of Business Administration, The University of Michigan and in alliance with the Society of Human Resources Management*, vol. 46, no. 3, pp. 395–409, 2007.

[45] J. T. Flinn, A. Miller, N. Pyatka, J. Brewer, T. Schneider, and C. G. Cao, "The effect of stress on learning in surgical skill acquisition," *Medical teacher*, vol. 38, no. 9, pp. 897–903, 2016.

[46] G. Borghini, P. Aricò, I. Graziani, S. Salinari, Y. Sun, F. Taya, A. Bezerianos, N. V. Thakor, and F. Babiloni, "Quantitative assessment of the training improvement in a motor-cognitive task by using eeg, ecg and eog signals," *Brain topography*, vol. 29, no. 1, pp. 149–161, 2016.

[47] S. Hwang, H. Jebelli, B. Choi, M. Choi, and S. Lee, "Measuring workers' emotional state during construction tasks using wearable eeg," *Journal of Construction Engineering and Management*, vol. 144, no. 7, p. 04018050, 2018.

[48] K. Izzetoglu, M. E. Aksoy, A. Agrali, D. Kitapcioglu, M. Gungor, and A. Simsek, "Studying brain activation during skill acquisition via robot-assisted surgery training," *Brain Sciences*, vol. 11, no. 7, p. 937, 2021.

[49] D. Sutton, "Cooking skills, the senses, and memory: The fate of practical knowledge," in *food and culture*. Routledge, 2018, pp. 88–109.

[50] A. Horowitz, *Inside of a dog: What dogs see, smell, and know*. Simon and Schuster, 2010.

[51] J. F. Hopstaken, D. Van Der Linden, A. B. Bakker, and M. A. Kompier, "A multi-faceted investigation of the link between mental fatigue and task disengagement," *Psychophysiology*, vol. 52, no. 3, pp. 305–315, 2015.

[52] J. D. Morgante, R. Zolfaghari, and S. P. Johnson, "A critical test of temporal and spatial accuracy of the tobii t60xl eye tracker," *Infancy*, vol. 17, no. 1, pp. 9–32, 2012.

[53] M. Elhelw, M. Nicolaou, A. Chung, G.-Z. Yang, and M. S. Atkins, "A gaze-based study for investigating the perception of visual realism in simulated scenes," *ACM Transactions on Applied Perception (TAP)*, vol. 5, no. 1, pp. 1–20, 2008.

[54] C. Pawelke, F. Merkle, D. Kurtovic, S. Gierig, and G. Müller-Plath, "Comparison of a perfusion simulator to a clinical operating room: evaluation of eye tracking data and subjective perception. a pilot study," *Perfusion*, vol. 37, no. 1, pp. 19–25, 2022.

[55] A. B. Yusuf, A.-L. Kor, and H. Tawfik, "A simulation environment for investigating in-flight startle in general aviation," in *2019 10th International Conference on Dependable Systems, Services and Technologies (DESSERT)*. IEEE, 2019, pp. 180–185.

[56] S. Sadasivan, J. S. Greenstein, A. K. Gramopadhye, and A. T. Duchowski, "Use of eye movements as feedforward training for a synthetic aircraft inspection task," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, 2005, pp. 141–149.

[57] N. J. Holter, "New method for heart studies," *Science*, vol. 134, no. 3486, pp. 1214–1220, 1961.

[58] R. Gajda, "Is continuous ecg recording on heart rate monitors the most expected function by endurance athletes, coaches, and doctors?" *Diagnostics*, vol. 10, no. 11, p. 867, 2020.

[59] H. J. Park, D. Choi, H. A. Park, and C. A. Lee, "Nurse evaluation of stress levels during cpr training with heart rate variability using smartwatches according to their personality: A prospective, observational study," *PloS one*, vol. 17, no. 6, p. e0268928, 2022.

[60] Festo. About festo. [Online]. Available: https://www.festo.com/gb/en/e/about-festo-id_3847/

[61] G. i. c. Festo and automation company. Festo machine. [Online]. Available: https://www.festo.com/rep/en-au_au/assets/Stoppen-Greifen-Spannen_22313u_2_500px.jpg

[62] (2022) Festo valve assembly line control system. [Online]. Available: https://www.festo.com/rep/en-ae_ae/assets/valve-assembly-line-control-system-16977c_34-710x270.jpg

[63] B. S. I. Sharp Brain Zone. 3d wooden brain teaser puzzle). [Online]. Available: https://cdn.shopify.com/s/files/1/1491/4668/products/2_5c75fa04-1761-4153-b979-702c908929b0_1024x1024\spacefactor\@m{}2x.jpg?v=1527236905

[64] S. Master. Rubiks cube inventor. [Online]. Available: https://rubiks.com/

[65] ——. Rubik cube 3x3. [Online]. Available: https://rubiks.com/productdetails/778988419533

[66] L. A/S. Lego mindstorms education ev3. [Online]. Available: https://tinyurl.com/legoexpansion

[67] G. Bule. The lock picking hobbyist. [Online]. Available: https://www.secjuice.com/content/images/2019/06/CuriousSmith3.jpg

[68] R. source. How to lockpick pad lock. [Online]. Available: https://images-na.ssl-images-amazon.com/images/I/51FzMs-PafL._AC_.jpg

[69] A. Housholder, J. Reaban, A. Peregrino, G. Votta, and T. K. Mohd, "Evaluating accuracy of the tobii eye tracker 5," in *International Conference on Intelligent Human Computer Interaction*. Springer, 2021, pp. 379–390.

[70] M. Tonsen, C. K. Baumann, and K. Dierkes, "A high-level description and performance evaluation of pupil invisible," *arXiv preprint arXiv:2009.00508*, 2020.

[71] T. Pro. Tobiipro glasses 2. [Online]. Available: https://tinyurl.com/tobiipro

[72] E. Inc. (2011) E4 wristband. [Online]. Available: https://www.empatica.com/assets/images/e4/2/e4_hero_device-lg-hdpi.jpg

[73] Y.-S. Wang, C.-L. Tai, O. Sorkine, and T.-Y. Lee, "Optimized scale-and-stretch for image resizing," in *ACM SIGGRAPH Asia 2008 papers*, 2008, pp. 1–8.

[74] W. Osberger and A. J. Maeder, "Automatic identification of perceptually important regions in an image," in *Proceedings. Fourteenth International Conference on Pattern Recognition (Cat. No. 98EX170)*, vol. 1. IEEE, 1998, pp. 701–704.

[75] (2022) Eventronic lock picking set, 30-piece lock pick set with 4 transparent training locks and manual and zip case for lockpicking. [Online]. Available: shorturl.at/APRW0

[76] (2022) Lego® mindstorms® ev3 31313. [Online]. Available: https://www.lego.com/en-gb/product/lego-mindstorms-ev3-31313

[77] T. AB, "Tobii pro lab," Computer software, Danderyd, Stockholm, 2014. [Online]. Available: http://www.tobii.com/

[78] ——, *Tobii Pro Lab User Manual*, Computer software, Danderyd, Stockholm, 2014. [Online]. Available: http://www.tobii.com/

[79] M. Garbarino, M. Lai, D. Bender, R. W. Picard, and S. Tognetti, "Empatica e3—a wearable wireless multi-sensor device for real-time computerized biofeedback and data acquisition," in *2014 4th International Conference on Wireless Mobile Communication and Healthcare-Transforming Healthcare Through Innovations in Mobile and Wireless Technologies (MOBIHEALTH)*. IEEE, 2014, pp. 39–42.

[80] Empatica. E4 wristband. [Online]. Available: https://support.empatica.com/hc/article_attachments/360031600212/blobid0.png

[81] ——. Empatica e4 specification. [Online]. Available: https://support.empatica.com/hc/article_attachments/360000797783/e4_specs.jpg

[82] C. Parker, S. Scott, and A. Geddes, "Snowball sampling," *SAGE research methods foundations*, 2019.

[83] M. S. Gide, L. J. Karam *et al.*, "Computational visual attention models," *Foundations and Trends® in Signal Processing*, vol. 10, no. 4, pp. 347–427, 2017.

[84] P. F. Drucker, "Management: tasks, responsibilities," *Practice*, vol. 125, 1973.

[85] *Cambridge Academic Content Dictionary, Cambridge Business English Dictionary* . Cambridge University Press.

[86] A. Kidd, "The marks are on the knowledge worker," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ser. CHI '94. New York, NY, USA: Association for Computing Machinery, 1994, p. 186–191. [Online]. Available: https://doi.org/10.1145/191666.191740

[87] M. D. Godfrey and D. F. Hendry, "The computer as von neumann planned it," *IEEE Annals of the History of Computing*, vol. 15, no. 1, pp. 11–21, 1993.

Appendix A

Participant Information Sheet

PARTICIPANT INFORMATION SHEET
(Version 1.1, Date: 22/08/2022)

Project Title:
Capture tacit knowledge

Contact Details:

Pranjal Jain (pranjal.jain@swansea.ac.uk)
Dr. Simon Robinson (s.n.w.robinson@swansea.ac.uk)
Reach out to us if you need any clarity or support regarding participation and research.

1. Invitation Paragraph

On day-to-day basis we use various tools for performing our daily work that we learn on the go. This project would like to learn how you use a tool. Hence, we would like to invite for a study where you could immerse yourself in learning lockpicking and Lego car robot.

2. What is the purpose of the study?

The purpose is to measure skill acquisition while doing lockpicking and making Lego car robot.

3. What time does the study take?

The study will take around 20 – 30 mins.

4. What will happen to me if I take part?

Participants will need to perform the following steps: 1) Complete the demographic questionnaire. 2) Wear eye tracking glasses and heart rate sensor on their body. 3) Activity 1st: Watch how to do lockpicking video and then do lockpicking by themselves. 4) Activity 2nd: Remove tyres of Lego car robot and reassemble them again.
Participants' gaze data and physiological data will be collected during the two activities, including heart rate and skin responses.

5. What are the possible disadvantages of taking part?

We do not expect any risk or disadvantage however in case of disadvantage participants can withdraw at any time without giving reason.

6. What are the possible options to withdraw from the study?

Participant is entirely voluntary, and you are not obliged to be involved. If you do participate you can withdraw at any given time without giving reason. If you do choose to withdraw, the data collected will not be used.

7. Will my taking part in the study be kept confidential?

Please be assured that only the researchers will have access to the raw data you provide. However, your data may be used in other related projects for an extended period in a secured manner. All the data will be collected and stored in accordance with the General Data Protection Regulation.

8. What if I have any questions?

Please contact us at the above email ids, if you wish to discuss the research further deciding whether to participate.

Appendix B

Participant Consent Form

PARTICIPANT CONSENT FORM
(Version 1.1, Date: 22/08/2022)

Project Title:
Capture tacit knowledge

Contact Details:

Pranjal Jain (pranjal.jain@swansea.ac.uk)
Dr. Simon Robinson (s.n.w.robinson@swansea.ac.uk)
Reach out to us if you need any clarity or support regarding participation and research.

Please initial box

1. I confirm that I have read and understood the information sheet dated 22/08/2022 (version number 1.1) for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐

3. I understand that sections of any of data obtained may be looked at by responsible individuals from Swansea University or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records. ☐

4. I agree to take part in the above study.

______________________________	________________	_________________________
Name of Participant	Date	Signature
______________________________	________________	_________________________
Name of Person taking consent	Date	Signature
Pranjal Jain ________________	_________________________	
Researcher	Date	Signature

Personal data collected on this form will be processed in line with the General Data Protection Regulation 2016 and the Data Protection Act 2018. Further information about how your data is managed is available on the University Research Privacy Notice.

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