Digitising and Enhancing the Training of Perceptual Expertise in Fingerprint Examiners Through Gamification

Bachelor Thesis

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1. Introduction

One of the most well-known usages in forensic science is the use of fingerprints at crime scene investigations as evidence to identify suspects and criminals and link them to crime scenes. Fingerprint examiners analyse and compare these prints with prints collected by a person, and come to a conclusion on whether there is a match. The results of such an analysis are significant, and if incorrect, can acquit a criminal or convict an innocent person of a crime.

Despite this, the process is far from perfect as human error and bias can occur when analysing a print [3]. These have resulted in several scandals in recent years, most notably with the Mayfield case in 2004, where an incorrect identification of a fingerprint was made, and an innocent was wrongfully detained and convicted of a crime [2, 3]. Some causes of this are a lack of standardisation in the documentation of the analysis process [3, 5], with different examiners having different ways and methods of documenting their analysis [3]. Some examiners even only present the results of their analysis without documentation in court [2].

While such practices should be reinforced and taught during training, this is not usually the case. The training procedure and even the number of years required to train to be a fingerprint expert can vary wildly around the globe, and there is no set standard on what needs to be accomplished and how many hours it takes to become a fingerprint expert. The utilisation of digital technology for training has also not been widely adopted in the industry, and while software exists that can assist in the work of fingerprint experts, their educational capabilities are still limited.

To mitigate such issues, this paper proposes the development of a digitised training platform utilising gamification in the training of fingerprint experts. Gamification is most commonly defined as the implementation of game mechanics and elements in a non-gaming environment and has been applied in educational settings with much success. To build up perceptual expertise, learners have to engage in repetitive and monotonous tasks, and the use of gamification is ideal to help engage and motivate learners in such tasks [12, 17]. Gamification has the potential to engage a user's intrinsic motivation by fulfilling their need for competence and autonomy which can greatly improve the training process [23].

The challenge is, therefore, in designing a digital gamified application that can supplement the training process of a fingerprint expert. The focus will be on training perceptual expertise rather than on any specific theoretical knowledge or sciences. The use of gamification specifically in the context of training fingerprint experts has been neither explored nor done before. The research question can therefore be formulated as:

How effective will the implementation of gamification be in enhancing the training process of building perceptual expertise in fingerprint examiners?

Several sub-questions can then be asked:

How effective will the implementation of gamification be in actively engaging learners?

How effective will the implementation of gamification be at satisfying a learner's need for competence and autonomy?

How effective will the implementation of gamification be at providing feedback to learners?

2. Background Research

2.1. Relevant Concepts

The processes and terminologies used in fingerprint analysis are likely unfamiliar to most people, and will therefore be covered here. Some of the more fundamental concepts are:

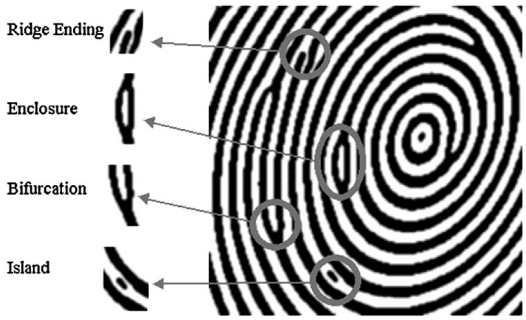


Fig. 1. Different characteristics (minutia) present in the friction ridge of fingerprints (e.g., when a ridge divides or ends) [23].

Exemplar Fingerprint: A fingerprint deliberately collected from a subject [6].

Friction Ridge: A raised portion of the epidermis on a fingerprint [6], in layman terms it is the lines observable on a fingerprint.

Latent Fingerprint: A partial fingerprint found at a crime scene [3].

Level 1 Detail: The pattern classification and flow of ridges [3].

Level 2 Detail: The minutiae of a fingerprint [3].

Level 3 Detail: Features uncommonly visible on fingerprints, such as pores and shapes of minutiae. These features are not usually required to be examined to form a conclusion [3].

Minutiae: The unique identifying characteristics of a fingerprint made up of ridge details [6].

Pattern Classification: The pattern type of a fingerprint that is defined by a classification system [6].

Fig. 2. 3 Basic fingerprint patterns [24]

ACE-V

At present, the leading methodology used in fingerprint analysis is the "ACE-V", which is an acronym for the four phases of fingerprint analysis, Analysis, Comparison, Evaluation, and Verification [2, 3, 8]. This methodology attempts to recreate the scientific method of forming and testing a hypothesis, analysing data, and coming to a conclusion with the hypothesis [3].

The analysis phase corresponds to the formation of a hypothesis. The examiner has to determine if the print is suitable for comparison [6], as well as identify and mark out the various details of the print, such as the pattern and any minutiae found [3].

The examiner then moves on to the comparison phase, where the hypothesis is tested [3]. The minutiae of the exemplar print are marked out against the minutiae of the latent print and compared with each other to identify any similarities and discrepancies between them [6]. When the examiner is confident that there is sufficient information to conclude, the examiner moves to the evaluation phase [3].

In the evaluation phase, a conclusion would then be made on whether the fingerprints are a match based on the similarities and differences between the latent and exemplar print [3, 6]. Three conclusions can be made, identification when both prints share enough similarities in details and belong to the same source [3], exclusion when both prints do not share sufficient details and do not belong to the same source [6], and inconclusive, where a conclusion cannot be made due to the lack of clarity in the latent print [3], which is the "amount of distortion, such as smudges, overlaid prints, and cloudiness" [3, pp. 12] present in the print.

Finally, the results would be verified through peer review in the verification phase [3], where the conclusion of the original examiner can either be supported or refuted by another examiner [6]. This can be done through blind or non-blind verification [3].

GYRO [4]

The GYRO system is a method of documentation that allows the examiner to mark out the confidence level of minutiae. GYRO stands for Green-Yellow-Red-Orange, which are the colours used for marking minutiae. Specifically, the use of GYRO allows the examiner to mark out the:

1. Level of certainty of the existence of the minutiae.
2. Amount of weight to assign to the minutiae during the comparison phase.
3. Expectation that the minutiae will be present in the exemplar print.
4. Tolerance for how different the minutiae will be between the latent and exemplar print.

A green mark is used to indicate a high level of certainty, expectation, and weight, and a low level of tolerance of minutiae. Likewise, a yellow mark will indicate medium levels for all of the

above. Red indicates a very low level of certainty and expectation, along with a high level of tolerance, and that the minutiae will be given minimal weight during the comparison phase.

The orange mark is used when a minutia was not observed in the analysis phase but was discovered only in the comparison phase. This allows the examiner to not have to exclude marks only found in the comparison phase while being transparent about it. This helps to prevent circular reasoning and cognitive bias associated with such an action. [4]

2.2. Literature Review on Gamification

To effectively apply gamification, it is important to study gamification through existing literature and identify what is known about it. This literature review will determine what gamification is, how it affects its users, and how to design for it. An existing taxonomy will be used to hone in on the individual elements which would allow the pinpointing of what each element is and how to use them rather than only looking at gamification as a whole. Through this literature review, gamification can be better understood and appropriately applied in the context of training fingerprint experts.

2.2.1. What is Gamification?

Gamification has been given many definitions and is the source of much debate. However, the most commonly defined definition provided in all the sources falls back to the one provided by Deterding et al., which is the use of game elements, such as "game technology, game practices, and game design" in "non-game contexts" [11, pp. 13]. Where games primarily provide a hedonic purpose, that is, to provide entertainment, gamification aims to combine that with a utilitarian purpose, to achieve something [16]. This purpose is usually to increase user motivation and engagement.

Perceptions of Game Elements

When people think of game elements, a combination of points, badges, and leaderboards tend to be the first things to spring to mind [13, 14, 16, 19]. It has even been coined the "PBL-triad" in research conducted by [21]. A taxonomy will be presented in the next section showing that there exist many other elements that do not receive as much attention but can be equally important.

Game elements such as the PBL triad are typically thought of as existing only in a gamified setting, such as in games. However, [13] proposes that it is the other way around. Ranks and medals in the army can be thought of as badges. Grades and honour degrees in schools can be thought of as points and badges respectively [13].

Such elements are considered gamification elements but are not perceived to be so, and [13] further theorises that these elements found their way into games from such non-gaming settings rather than the other way around. An example is how games such as Megaman rank (or grade)

your performance in a level. By simply altering its execution, the perception towards these elements can also be adjusted, making it more enjoyable and fun to engage with.

For example, a school, Quest To Learn, fully gamified their teaching process, converting concepts such as grades into being upgraded, and completing assignments to completing secret missions. By changing the perception of these existing concepts, it resulted in increased engagement with the students [13].

Intrinsic and Extrinsic Motivation

Throughout this review, the concepts of intrinsic and extrinsic motivation will be used to discuss the effects of gamification. Intrinsic motivation comes from within the learner, such as their interest in learning a topic to improve themselves. Extrinsic motivation comes from external factors such as gaining points and earning rewards in the educational environment.

2.2.2. A Taxonomy of Gamification Elements

Gamification is implemented through its different elements. These elements can be so varied and different in the ways they are implemented and used across different platforms, and they can be combined in many unique ways with unique outcomes. Therefore, it is beneficial to understand what each of these elements is, and how they can be used and affect the users, compared to looking at gamification broadly as a concept. This will also help to categorise the different names and implementations of an element in the rest of the paper as belonging to one specific element.

As such, a taxonomy of its elements has to be found and explored. The taxonomy chosen is from [12] as it focuses on the applications of game elements within an educational environment. The elements are categorised into 5 different dimensions, **Performance**, **Ecological**, **Social**, **Personal**, and **Fiction**, and will be discussed in the next section.

Fig 3. Gamification Taxonomy [12]

From this, we can investigate two points, the what and the how; What is each gamification element and what can it be implemented as? How does each element affect the user and how can it be used? In the context of describing these elements, intrinsic elements are subtly presented in the environment such that users may not notice them, whereas extrinsic elements are easily noticed by users [12].

1. Performance

Elements within **Performance** include:

a. *Points*
b. *Acknowledgement*
c. *Level*
d. *Progression*
e. *Stats* [12]

These elements serve as extrinsic feedback to the user's actions and are considered environmental responses [12].

a. *Points*

Can be implemented as any form of points [12, 14, 15, 17, 19, 21, 22] or as a score [12, 15].

Points is implemented as a numerical value that represents the player's progress. This element serves as granular and continuous feedback for the user [21] by rewarding users for their interactions and allowing them to keep track of their performance.

b. *Acknowledgement*

Can be implemented as badges [12, 14, 15, 20, 21], achievements [12], medals [12], trophies [12], high scores [17, 20], and special bonuses [20].

This acts as cumulative feedback and provides visual representation and confirmation of the user's accomplishments [21], praising and recognising their actions [12]. This can also serve as a goal-setting mechanism to direct user behaviour [12, 14, 21] or to provide instructions on how a system can work [14]. For example, awarding achievements on interacting with individual functionalities for the first time. However, if designed poorly, it may cause users to prioritise wrongly [12].

c. *Level*

Can be implemented as a skill or character level [12], or a chapter to be completed [20].

Level blocks progression and content until the user reaches a specific value [12], and can be tied to the number of *Points* the user has accumulated [12] or by completing a requirement in the environment [14].

d. *Progression*

Can be implemented as a progress bar [12, 20], steps [12], map [12], level [15], or accumulated points [12, 14, 15].

Progression shows the user their progress in the environment. *Progression* is typically tied to *Points*, where the user earns *Points* to advance *Progression* [12, 14, 15]. This element guides the user on where they are in the environment, helping them locate how far they have advanced [12].

e. Stats

Can be presented as information [12], heads-up display (HUD) [12], data [12], dashboards [12], profiles [14, 20], and performance graphs [21].

Stats is used to evaluate and display the user's performance over time [21], providing them with visual information about their interactions with the environment [22]. Displaying these elements in a compiled form provides empirical feedback on their performances, helping the user feel oriented, and also helps them focus on their positive developments [20].

2. Ecological

Elements within **Ecological** include:

a. Chance
b. Imposed Choice
c. Economy
d. Rarity
e. *Time Pressure* [12]

This dimension relates to the elements within the environment, hence the name Ecological, and how they respond to the user. [12], and can be used to direct user behaviour. These are extrinsic in nature, except for Chance.

a. Chance

Can be implemented as randomness, luck, fortune, and probability [12]

This is the intrinsic random property of an event or outcome which can be used to implement random quality (*Rarity*) and quantity of rewards and can be combined with strategies that mitigate bad luck [12].

b. Imposed Choice

Can be implemented as choices, judgements, and paths [12].

Imposed Choice is a forced decision the user has to make to advance in the environment, providing meaning to their choices [12] and giving them active agency in their decisions within the environment.

c. Economy

Can be implemented as a transaction, market, or exchange [12].

This is the exchange of a currency for something that the user can use to their advantage. This motivates users to perform better and engage more in the environment to acquire more currencies to gain an edge [12, 20]. But if not related to the content, it may cause users to focus instead on these extrinsic factors rather than intrinsic improvements [12].

d. Rarity

Can be implemented as limited items, collections, and exclusives [12].

Rarity relates to resources that are difficult to acquire. This can stimulate the user by engaging them to pursue a goal to acquire rare resources but can also demotivate them if it is overdone [12], such as by withholding important resources needed to progress in the environment and forcing them to grind for it.

e. Time Pressure

Can be implemented as deadlines [12, 20], countdown timer [12], clock [12], and curfews [20].

Time Pressure is usually implicit in learning environments but is considered highly irrelevant in gamification [12]. This can prevent boredom in the user by pressuring their actions [12] and can also motivate them to periodically return to the application [20]. However, it can potentially disengage the user if not enough leeway is given, which can be mitigated by providing flexible deadlines [12].

3. Social

Elements within **Social** include:

a. Competition
b. Cooperation
c. Reputation
d. Social Pressure [12]

This dimension relates to the interactions between the users in the environment, connecting them. This motivates them to outperform, collaborate, or help each other and prevents users from feeling isolated. These interactions are intrinsic [12].

a. Competition

Can be implemented as conflict [2], leaderboards [12, 14, 15, 20, 21], scoreboards [12], and player vs player (PvP) [12, 14]

Competition causes *Social Pressure* by pitting [12] or comparing user performances against each other [20, 21]. This can be motivating for users who are close to catching up with their peers [12,

14, 21], but can have the opposite effect if the user is underperforming, demotivating them as advancing seems unattainable [12, 14, 21].

Some ways to mitigate this can be to not tie the competition to any content-based activity [12], having users compete in groups to not isolate any individual user [12], using an indirectly competitive leaderboard that tracks relative progress instead of direct results [14], and designing it so that only users around the same skill level compete with each other [21]. It was further suggested to design for underperformers [18].

b. Cooperation

Can be implemented through teamwork [12, 20], co-op [12], and forming groups [12, 14].

The opposite of *Competition*, this element creates *Social Pressure* through collaboration between users rather than pitting them against each other [12], but can still be used with *Competition*. Fostering collaboration encourages users to share knowledge and work harder to not let each other down [12].

c. Reputation

Can be implemented as classification [12], status [12], title [12], profile [14, 20], avatar [15, 20, 21], or level [20]

Reputation is used to display the social status of users [12], usually with elements in the Measurement dimension. Unlike *Level*, this is not related to the skill of the user and instead acts as a virtual social symbol [12, 21]. This allows a discreet way of flaunting achievements and accomplishments without explicitly bragging [14] and can also create social hierarchies within the environment [12]. *Reputation* can typically be implemented with *Stats* as both show information about the user.

d. Social Pressure

Can be caused by peer pressure [12, 20], guild missions [12], peer-review [12, 15], project work [14], and teammates [14]

Social Pressure pressures users to perform better to not let their peers down or through persuading users to help each other [12], This can increase engagement, learning, and participation in users [21]. [20] adds that Social Pressure helps simulate a classroom environment and community, and receiving recognition from their peers can motivate them as well.

4. Personal

Elements within **Personal** include:

a. Novelty

b. *Objective*
c. *Puzzle*
d. *Renovation*
e. *Sensation* [12]

This dimension relates to the user and its elements are intrinsic. They are usually found in educational environments and not viewed as gamification elements [12].

a. *Novelty*

Can be presented as updates [12], surprises [12], changes [12], or variety [12, 14].

Novelty is any form of new changes and content in the environment that prevents stagnation in the content, preventing the users from becoming disengaged and unmotivated [12].

b. *Objective*

Can be implemented as missions [12], side-quests [12], milestones [12], goals [12, 13, 15], and curriculum [14, 15, 17].

Objectives are typically the learning objectives of the user in the environment [2], but can also be the goal of a smaller part of the environment [15], providing the user with a purpose to strive for [12] and motivating them to perform the required tasks [15].

c. *Puzzle*

Can be implemented as challenges [12], cognitive tasks [12, 14, 15, 17], actual puzzles [12], exercises [15], and work [14, 15].

Puzzles are the learning activities and challenge the user completes to advance towards their Objective [12]. It is essential to gamification, providing extrinsic rewards or fulfil their intrinsic needs for completing them [21, 22].

d. *Renovation*

Can be implemented as boosts, extra life, or renewal [12].

Renovation involves the re-doing of tasks from the user, for example, if they have failed or wish to remind themselves of the content of the task. This makes the tasks fun by giving them a second chance. A lack of it results in tedium, which makes the environment difficult and demotivating [12]. It should be used when the user is still mastering a piece of knowledge or skill, rather than being tested by it.

e. *Sensation*

Can be achieved through dynamic and gameful interfaces [12], virtual and augmented reality [12], animations [19, 22], and sound effects [17, 22].

Sensation is a highly relevant element that is simply visual or auditory stimulation [12]. Audio is only used in [17] but is not discussed further other than the fact that it was implemented. S*ensation* ensures that the user's interactions with the environment are pleasurable and enjoyable [12]. Through [19] and [22], this element can be linked to juiciness, as in the lens of juiciness in Schell's Art of Game Design [10]. [22] states that juiciness affords competence needs satisfaction through immediate and pleasurable experience.

5. Fiction

Elements within **Fiction** include:

a. Narrative
b. Storytelling [12]

Fiction elements are related to the context and story of the environment and are uncommon and usually not considered in gamification [12]. These elements tie the user experience to the environment, providing meaning and context to the interactions, and influencing the experience of the user [12].

a. Narrative

Narrative is an intrinsic element that is the order of events influenced by the user's implicit choices with the environment. It can be used to subtly reward users for desired behaviours, and help them focus on the content rather than the game elements [12].

b. Storytelling

Can be told through text, audio, or other sensorial resources, for example, audio queues, text stories, and storylines [12].

Storytelling is any form of a story that can be implemented through meaningful stories, contextual activities and characters, and game titles [21]. Its main purposes are to support the narrative, give meaning and context to the environment [20], and bring life to dull environments [21].

2.2.3. Effects of Gamification

The use of gamification in education is usually implemented to engage the user in the curriculum and course of instruction [18]. Gamified applications were found to make interactions more fun and enjoyable for users [13], with users responding positively towards gamification in [14, 15, 17] which consequently resulted in increased motivation and engagement in users. This positive

impact on motivation and engagement can also be observed in studies done in [14, 15,17-19], signifying that this is the most common outcome of gamified applications.

The effects of gamification on user performance and learning outcome, however, while leaning towards having a positive effect on performance, was not as universally agreed upon. In studies performed and observed in [13-15, 18, 19], improvements in performance and learning outcome were found when gamification was implemented. However, [17] found no significant effect on performance and learning outcome. This was also backed up with findings from other literature stating that gamification does not improve performance. This shows that the effects of gamification on performance and learning outcomes are still under much debate.

2.2.4. Designing for Gamification

While the presence of gamification has been found to have positive effects, this does not mean that game elements should be blindly implemented in gamified applications [18]. The presence of these elements does not guarantee the found effects of gamification, and an awareness of how and when such elements should be used is crucial [21]. This may explain the discrepancies of results in the various studies that find different results of learning outcomes from the use of gamification. This section will review the strategies, mechanisms, and design processes of gamification, to better understand how to design for it.

Strategies for Implementing and Designing Gamification

[20] provides several strategies for designing educational gamification content. Content can be separated into different chapters, topics, or sections, utilising the cascading information principle, making the content more coherent and digestible. Each of these sections should also provide detailed information on theoretical knowledge of the content that learners can study on. Practical challenges should also be offered, such as exercises and evaluations. To "maintain the flow of learning" [20, p. 328], learners should always be kept informed about what the next steps of their education should be, which can keep them engaged and excited about the content.

Heavy use of elements within the **Performance** dimension was recommended by [20]. *Points* should be awarded for completing sections, which advances their *Levels,* unlocking new content. Offering constant feedback was emphasised through the use of *Progression*, which helps inform learners about their progress in the environment. Although not mentioned, the use of *Points* as granular feedback to every of the user's actions and the use of *Stats* to inform learners about their performances over time can also help provide constant feedback. Finally, *Acknowledgements* should be awarded not just for academic achievements and accomplishments, but also for good social behaviour such as engaging and helping their peers.

[20] also suggests emphasising **Social** elements to stimulate a classroom environment. For example, learners may be motivated through *Peer Pressure* and *Competition*, such as the use of indirectly competitive leaderboards [4] to track the relative positioning of learners against their

peers. The use of *Reputation* in the form of an avatar and a personal profile is also recommended, allowing learners to keep up to date with social and educational information.

The use of some **Ecological** elements was also recommended. *Economy* could be implemented to allow learners to convert *Points* and *Acknowledgements* to gain an advantage in the environment. This can motivate them to perform better to earn more *Points* and *Acknowledgements* and engage more with the application. The use of *Time Pressure* as deadlines, and periodical appointments can also motivate learners to return to the application occasionally.

One strategy is relevant to the training of fingerprint experts. Perceptual learning can be repetitive and monotonous, requiring repeated exposure of stimuli to the learner to build perceptual expertise [17]. Therefore, the use of gamification can be especially helpful to maintain the learner's engagement to the task [17, 18]. [18] proposes the use of game elements that provide feedback, such as *Points* and *Progression*, and the use of *Time Pressure* to provide excitement and a sense of urgency to an otherwise dull and repetitive task.

Psychology of Gamification

The mechanisms that allow gamification to work are deeply rooted in psychology [16, 19, 21]. This is not surprising as gamification works through directing, encouraging, or changing user behaviours to the desired one [16, 19-22]. An important concept that explains the mechanisms of gamification is the self-determination theory, which was discussed in [19, 21, 22]. According to [23], there are 3 psychological needs in self-determination theory that need to be satisfied to increase and engage intrinsic motivation; the need for autonomy, the need for competence, and the need for relatedness.

The need for autonomy relates to the need for volition from the learner, and the ability and freedom for the learner to self-organise their behaviour and have their actions align with their needs [23]. The need for competence relates to the need for efficacy through challenges that allows them mastery of a skill [23]. The need for relatedness relates to the need for connection to others [23]. Of these, the need for autonomy and competence were found to have the strongest impact on intrinsic motivation [23]. Furthermore, feelings of competence would not affect intrinsic motivation without also satisfying the need for autonomy [22].

The use of gamification and extrinsic motivators can engage these psychological needs to increase the motivation and engagement of users in an application [20]. In a study conducted by [21], it was found that the use of *Acknowledgement*, *Stats*, and *Competition* were found to foster the need for competence, and a part of the need for autonomy, specifically on needs satisfaction. The use of *Reputation*, *Cooperation*, and *Storytelling* was found to foster the need for relatedness.

Such effects are not guaranteed, however. In a study conducted by [22], the implementation of gamification did not affect any psychological need and even negatively affected the performance

of users. Users were asked to generate tags for images and were subsequently scored on the number of tags given. There were several shortcomings of the experiment.

Users were only scored on the number of tags generated, and were given no information or feedback on their performance and so could not judge how they were performing. The presentation of the feedback was also lacklustre and lacked juiciness. The tasks to be performed were also found to be of little challenge to the users and were not perceived to be gameful or containing any game elements at all.

The study also found that performance decreased when users were more motivated to generate more tags. This is correlated with [17] which found that participants who took their time completing tasks had better performance. This is essential when implementing gamification to train fingerprint experts, as the process of fingerprint analysis should also not be rushed and learners should prioritise accuracy over speed [3]. Essentially, the goal of gamification has to align with the goal of the user, and rewards have to be appropriate to the context of the task or learning goal [18].

There are other pitfalls to be considered, especially in implementing extrinsic rewards. In the context of education, learners have to primarily be intrinsically motivated by the content [18]. It has been found that the presence of extrinsic rewards can undermine intrinsic motivation [18, 23] and can make users feel controlled by these rewards rather than their actions being their choice, which can undermine their feelings of autonomy [23]. Providing negative feedback can also cause perceived incompetence, undermining feelings of competence [23].

To avoid these pitfalls, gamification has to be designed so that it is not reliant on extrinsic rewards [18]. Autonomy can be provided by emphasising user choices and freedom [18, 23], and allowing them to set their own goals, which can "minimize the potential controlling aspect of rewards and instead strengthen their competence-affirming aspect" [18, p. 33]. However, such negative effects are safe when gamification is used for one-time activities or activities that are dull and boring [18].

Design Processes

HCI processes were identified as being crucial in designing gamification [19], with the vast majority of gamified apps predicted to fail due to a lack of understanding of these design processes [16].

One such process is the importance of designing for stakeholders. This includes identifying the target audience [16, 18, 19], understanding the user needs and requirements [16, 19], involving stakeholders in the design process [16, 19], and investigating the context of deployment through context analysis [16, 19].

Identifying the target audience can help determine the intended usage of the application, and to design specifically for that. For example, learners who are highly competitive with little spare

time may benefit the most from short interactions with the application [18]. Users and stakeholders may also have certain requirements that cannot be predicted without their input, and it is essential to understand these requirements as early as possible to prevent inappropriate designs from being too embedded in the system [19]. It is therefore important to involve such stakeholders in the design process and to consult with them frequently. Understanding the context can also help provide a goal for gamification, which would make it easier to design and evaluate the project [18]. Specifically, gamification should be designed with a clear and achievable goal instead of blindly implementing it.

[16] provides a comprehensive guide for designing gamification, along with activities to be completed at every phase of the project. The authors identify seven phases of development:

1. Project Preparation
2. User and Context Analysis
3. Ideation
4. Design
5. Implementation
6. Evaluation
7. Monitoring

Of these, monitoring will be ignored as it will not be relevant in the context of this project. Thirteen design principles were also developed [16, p. 224], which were then mapped to the above phases. The activities related to each phase will be discussed.

8. Project Preparation

In this phase, the objectives of gamification are to be identified and clarified. These should then be ranked in order of importance as a list of objectives. Each of these objectives should then be justified on how they benefit the stakeholders. From there, it can then be assessed if gamification is suitable for the project.

9. User and Context Analysis

In this phase, the goal is to gain an understanding of the target audience and the context of implementation that gamification will be implemented within the application. The context of the project should be identified and understood, along with metrics that can define the success of the project. In addition to the context, the target users have to be defined and identified as well, along with their motivations. These should then be translated into a persona.

10. Ideation

This phase concerns the development of a gamification design. Ideas should be brainstormed based on the identified user needs and context and compiled together, before being consolidated based on the fit between the idea and the user needs and context.

11. Design

Following ideation, concrete gamification designs have to be developed and prototypes. Prototypes of the consolidated ideas should be designed, created, and evaluated with user feedback through playtesting. Once the design is finalised, a development plan can be made to determine the specifications of the implementation.

12. Implementation

The design will finally have to be executed and brought to life. A decision will have to be made on the platform of development, and any further requirements such as the use of fingerprint databases have to be handled.

13. Evaluation

Finally, the project can be evaluated on its success through qualitative and quantitative methods.

2.3. State of the Art Educational Software

While gamification has not been utilised to train fingerprint experts, some software has been developed that can be used in an educational capacity in the training of fingerprint experts. These products will be reviewed, discussing the features for annotations and documentation available, and the training functionalities.

2.3.1. PiAnoS

PiAnoS, which stands for Picture Annotation System, is an interface developed to annotate and conduct fingerprint analysis and comparison through ACE-V [4]. A unique feature is that PiAnoS does not allow annotations and documentations made in the Analysis phase to be edited after that phase is completed [4].

Within the Analysis phase, several tools can be utilised to mark out features and minutiae in a print. The quality tool allows the marking of surfaces and zones of different colours to indicate the perceived quality of that area. Two standards can be used, a three-point system indicating good, moderate, and weak quality, or a 6 level system. The minutiae tool allows the annotation of minutiae on a fingerprint. Only bifurcations and ridge endings can be marked out, in addition to minutiae which has an unknown type but known location (type unknown), and minutiae which has an unknown position but a known type (position unknown). Ridge flows in the fingerprints can also be traced using the ridge tracing tool [9], and features such as creases, scars, and other level 3 details can also be marked out [9].

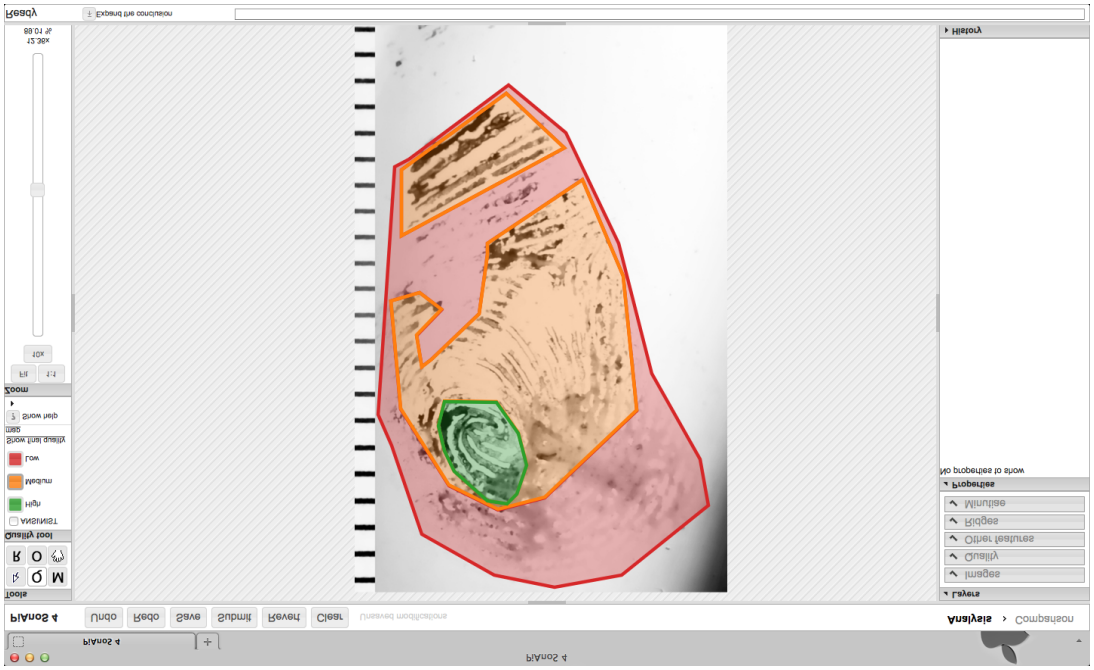


Fig. 4. Quality annotations of the mark [9].

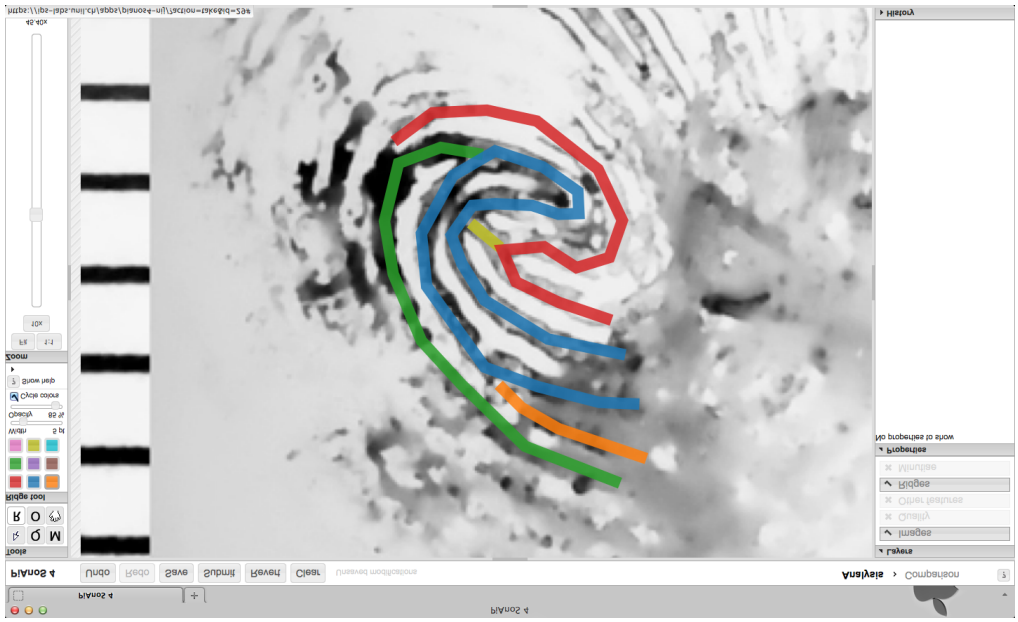


Fig. 5. Example of tracing a few ridges on the mark [9].

When concluding the Analysis phase, a questionnaire has to be answered to declare the general degradation aspects observed on the mark, the quality of level 1, 2, and 3 details on the print, the suitability approach used, the suitability of the latent mark, and a free text section to document additional observations [9].

Within the Comparison phase, all of the above tools are available to be used. In addition, several other tools are available.

Both the latent and exemplar print can be bound together so that movements on one image also moves annotations on the other image. Minutiae found in only one print can also be marked with a “Difference” minutiae on the print missing that minutia. Finally, minutiae that match on both prints can be paired together by numbering them [9].

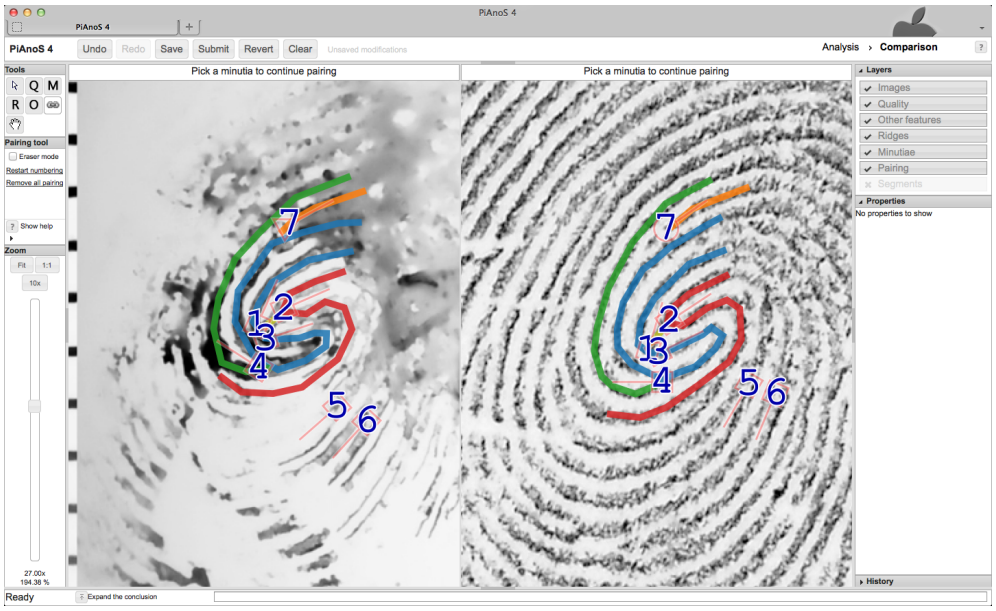


Fig. 6. The pairing of all “matching” minutiae using the Pairing tool (P) [9].

The conclusion of the Comparison phase is essentially the Evaluation phase, where the examiner has to come to a conclusion. Similarly, a questionnaire is provided, where the examiner has to provide a final conclusion of identification, exclusion, or inconclusive, whether level 3 details contributed to the conclusion, the quality and quantity of features used during the Comparison phase, and a free text section to document the Comparison phase.

There does not seem to be any functionality for Verification.

PiAnoS features an educational tool, so-called the “tutor” mode by [4], in which annotations made by multiple students can be displayed simultaneously and anonymously, allowing critical feedback to be provided to the student.

2.3.2. ACEware [5]

ACEware is a software platform that provides “standards-based detailed annotation of the latent print examination process” [5, p. 5]. It is built upon the Universal Latent Workstation (ULW) which provides tools to annotate and perform comparisons of fingerprint images. ACEware extends the functionalities of ULW by also providing training capabilities.

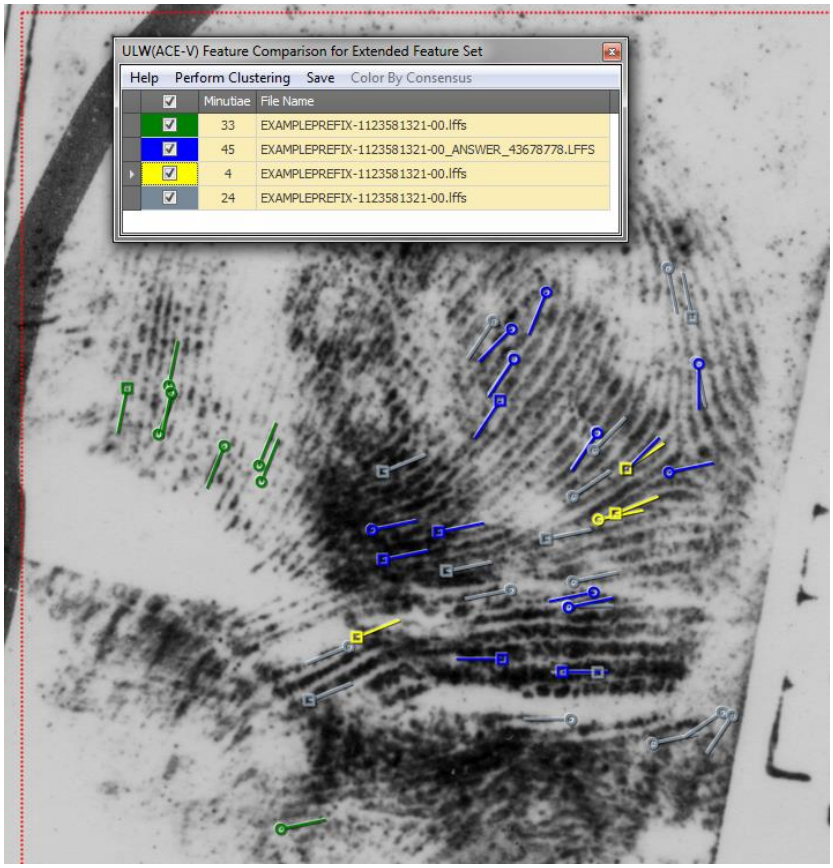


Fig. 7. Multiple student's markups, including answer files, on a single image [5]

Notably, ACEware allows the facilitation of both instructor training through classroom tutorials, self-led training, and peer evaluation. It allows instructors to create and run lessons, and review the works of students. For image or search files, students can be graded based on how well the annotations of minutiae match with an answer file. For a COMP (Comparison) file, statistics are provided on several data points as shown in Fig. x. Similar to PiAnoS' tutor mode, ACEware also allows simultaneously displaying the annotations of several students at once anonymously, facilitating discussion within a classroom. These features are all also available for students to use so that they can take charge of their training [5].

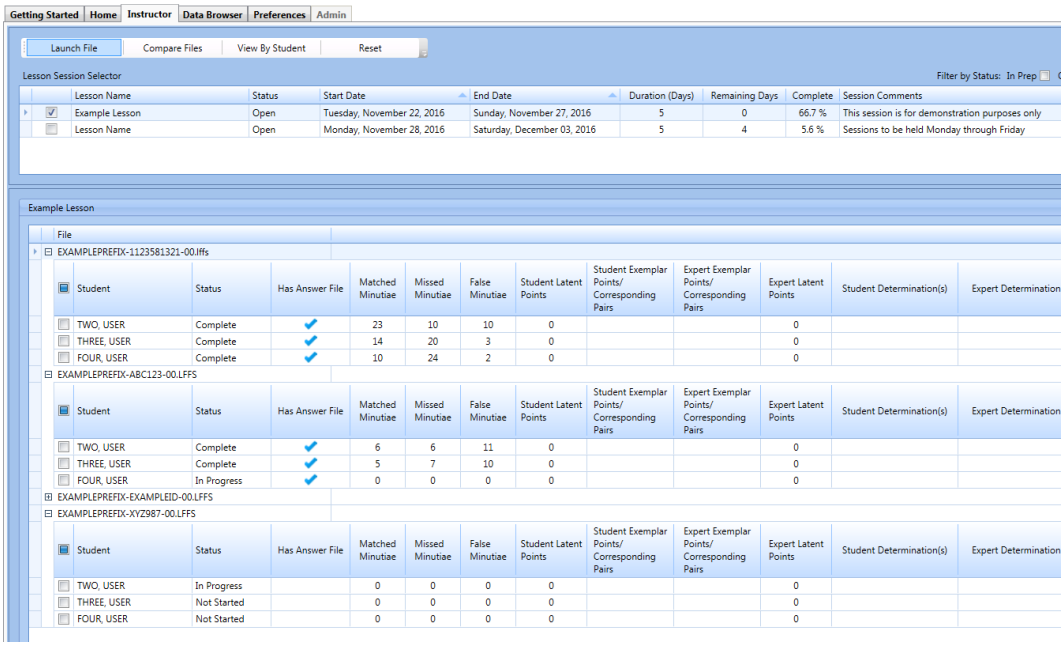


Fig. 8. Instructor dashboard [5]

ACEware also provides additional features to facilitate casework. Unlike PiAnoS, ACEware supports the ability to verify another examiner's work, and also allows assigning of examiners to perform verification. Depending on the results, the status of the verification can be "Verified" indicating the same determination from both examiners, "Conflict" indicating different conclusions, and "Critical Conflict" which is not clear what it means. Quality Assurance Reports are also automatically provided when a low amount of minutiae is marked in a print or a low number of minutiae are retained between the analysis and comparison phase [5].

3. Requirements Capture

In this section, the first steps of the design process are described. Specifically, the objectives of the project will be reviewed, and the essential contents of a course will be developed to train complete beginners from the ground up on fingerprint examination skills. This will all be done through consultations with the client.

The nature of this project meant that as a developer developing educational content for fingerprint examiners, I had zero practical experience with actual annotation, and many of the details of what would be taught or is important to be taught in the line of work were still unclear as it was a completely foreign subject matter. As such, it was difficult to know exactly what should be designed early on, even after repeated consultation with the client. The requirements capture and ideation phases will, therefore, only be able to provide a very broad and general idea of what could or should be designed. In such a case, it proved more useful to implement actual interaction earlier rather than later and iterate on that.

3.1. Target Audience

While the project was originally envisioned to be used by fingerprint examiners in training, it was eventually deemed to be out of scope as building an application to teach more advanced concepts may be too complicated to achieve within the given time frame. Furthermore, fingerprint examiners in training may have vastly different skill levels and existing training which can be difficult to control.

As such, the client has recommended the use of complete beginners with no knowledge of fingerprint examination. The reasoning behind this is that if the application is effective in training complete beginners, it can also be equally effective in training others of varying skill levels. The demographics of such users can be very broad, as fingerprint examiners in training can be of vastly different ages. However, users should preferably have university experience.

A limitation of such a target audience is that intrinsic motivation for such a topic may differ greatly between participants, and will no doubt be much lesser than participants who had already chosen to study or pursue this field. This can however be used as a metric of how effective the implementation of gamification is in motivating and engaging its users.

3.2. Objectives

To know what to design, it is important to know what we are designing for, specifically, what are the objectives that this product should achieve, and what are the objectives of gamification. Broadly, the objective of the product is to train complete beginners with the bare minimum knowledge necessary to understand and perform ACE-V. This can specifically be divided into 3 sub-objectives:

1. To build up fundamental theoretical knowledge of learners on fingerprint examination.

This entails an understanding of what the field is, its importance, its various terminologies, and its processes.

2. To build sufficient perceptual expertise that learners can identify and differentiate various fingerprint characteristics and details.

This requires learners to be able to identify different patterns and minutiae in a fingerprint and differentiate between them.

3. To familiarise learners with the ACE-V methodology so that they can independently work with it.

Learners have to be familiar with what ACE-V is and its processes and be able to use it to form a conclusion.

With regards to the objectives of gamification, these are based on the research questions, 3 objectives can be identified that this project will attempt to accomplish. These are:

1. *Actively engage learners in repetitive and monotonous tasks.*
2. *Incrementally train fingerprint examiners?*
3. *Track stats to provide empirical evidence and feedback.*

3.3. Required Fundamental Knowledge

The following content will be essential in allowing learners to understand the context of the work they are doing and to familiarise themselves with theoretical aspects of the field. Before working with ACE-V, learners also need the skills required to analyse a print, which will heavily involve the training of perceptual expertise and being able to identify specific fingerprint features. The following content will be essential in allowing learners to understand the context of the work they are doing and to familiarise themselves with theoretical aspects of the field. At all stages, best practices in documentation standards would also be described to the learners.

1. Background knowledge on the field and basic knowledge of relevant terminologies and processes.
    a. Context and background information on the field.
    b. Introduction to fingerprints.
    c. Introduction to methodologies and techniques.
2. Fingerprint Features
    a. Friction Ridges
    b. Pattern Areas
    c. Type Lines

    d. Delta
    e. Core
    f. Ridge Count
    g. Minutiae
3. Fingerprint Patterns
    a. Loops
    b. Whorls
    c. Arches
4. Methodologies and Techniques
    a. ACE-V
    b. GYRO

4. Ideation

This section will describe the ideation of the application based on an existing vision. Brainstorming of how the gamification elements as described from the taxonomy of [12] will be performed based on their relevance and how they can improve the education process. These ideas form the initial concepts of the application and the development of the application will build upon them.

4.1. Existing Vision

This section will describe the existing vision of the application that developed throughout the project until this point. These existing visions are ideas on how the application may function and what can be done within it. From these ideas, clearer specifications will be developed in the next section.

4.1.1. Annotation Exercises

From early on, there was already a vision for the practical aspects of the application. These were the parts where learners would train on their perceptual expertise and annotate features in a fingerprint. Much of this vision came from the initial discussions with the client, who suggested a grading system through GYRO annotations. Therefore, the idea to have annotation exercises for theoretical lessons was always there. These annotation exercises would have the learners annotate specific details on a random fingerprint, which would then be matched and graded against an existing answer sheet annotated by preferably an expert. As such, building a tool for annotation would be central to the application.

4.1.2. Enforcing Annotation and Documentation Standards

In addition to annotation, standards regarding annotation and documentation of how a decision was made on annotations could potentially be enforced. This would build significantly on the content taught closer to the theoretical level, where learners would have to document the specific rules and standards applied in addition to annotating them. Therefore, it was envisioned that annotations would be accompanied by some form of note-taking feature and questionnaires that need to be filled and answered.

4.1.3. A platform for Collaboration and Peer Review

One of the ways grading could be performed for the above features would be to have learners peer review each other's work. Learners would each have their profiles and be connected in the application. Annotations would be filed and saved in the system where learners could anonymously review each other and discuss the ways each person documented or chose to annotate specific details. In this way, it is hoped that an open culture of discussing each others' work could be fostered in such an environment.

4.1.4. Progression of Content

The content was envisioned to be separated into different programmes. Within each programme, content could then be further separated into courses, with each course having content either being lessons for theoretical content, or exercises for practical content.

3 programmes were envisioned; a Knowledge Programme, an ACE-V and GYRO Programme, and a Free Work Programme. The Knowledge programme would cover the required fundamental knowledge of the learner, as described in section 4.3. The ACE-V and GYRO Programme would have learners independently annotate random fingerprints while using and acclimatising to the ACE-V methodology and GYRO system. The Free Work Programme would be similar to the ACE-V and GYRO Programme, but would leave the learners to be completely independent on which prints they wish to analyse if any, and can freely verify others' works.

4.2. Considerations for a Gamified Design

Based on the background research, several considerations have to be taken into account when designing for gamification elements:

1. Elements cannot just be implemented in any form, but have to be fun or perceived to be enjoyable to have a positive impact on the user.
2. Gamification needs to be relevant to the content. The objective of gamification must be identified, and if it does not serve the content, should be removed.
3. Content should be separated into different sections to make it more digestible.
4. Theoretical content should be followed by practical content to allow learners to be evaluated at every stage.
5. Learners should be aware of what they will be learning in the bigger picture to keep them engaged and excited about the content.

4.3. Brainstorming Gamification Elements

A large part of the background research in this paper was dedicated to exploring various gamification elements and understanding how they may be utilised. In this section, each gamification element will be discussed to identify how they may be appropriately implemented within the environment. This will be accompanied by identifying how that implementation is relevant to the content to avoid the pitfall of designing elements that do not serve any purpose other than providing extrinsic motivations.

Performance Dimension		
Element	**Possible Implementations**	**Purpose of Implementation**
Points	Awarded points for correct	Providing instant feedback on

	annotations	learners' performance and answers.
Acknowledgement	Awards/badges for accomplishments and milestones the learner achieves	Provides granular feedback on the learners' efforts, especially when it is considerable. Provides learners with goals to strive for.
Level	Unlockable course content	Helps streamline content and not overwhelm the learner. Provides the learner with information about what they are learning.
Progression	Progress bars showing progression in a course	Provides feedback on learners' accumulated efforts.
Stats	Profile page showing various statistics on learners' performances.	Provides accumulated long-term feedback on how the learner is performing overall. Can also be used to identify weak areas for a learner.
Ecological Dimension		
Chance	Not implemented	
Imposed Choice	Not implemented	
Economy	Not implemented	
Rarity	Not implemented	
Time Pressure	Not implemented	
Social Dimension		
Competition	Leaderboard of relative progress in the application.	Allows learners to locate themselves compared to other learners, and gives them the motivation to work harder to overcome or become equal to others.
Cooperation	A peer-review process, which	Foster a sense of community

	will be required to earn *Points* and progress in *Level*.	and cooperation that is essential in the field of work.
Reputation	Public profile visible to others if they so choose.	Helps users feel a sense of ownership towards their work in the application.
Social Pressure	Not implemented	
Time Pressure	Not implemented	Not relevant to the field, learners should take their time understanding the topic and annotating details. Time pressure encourages the opposite.
Personal Dimension		
Novelty	Variety of educational content, exercises can have different features available based on which detail is being tested.	Helps keep the learner engaged and not become bored by learning the same content and performing the same tasks. Helps keep content varied.
Objective		
Puzzle	Annotation exercise	Allows the learner to put their knowledge to practical use. Helps the learner develop the required skills.
Renovation	Learners can complete exercises and review lessons as many times as they want.	Prevents learners from feeling frustrated, and allows them to revise older material.
Sensation	Profile page showing various statistics on learners' performances.	Provides accumulated long-term feedback on how the learner is performing overall. Can also be used to identify weak areas for a learner.
Fiction Dimension		
Narrative	Not implemented.	
Storytelling	Provide context and stories on	Provides meaning to the

	the fingerprints learners have to analyse and examine.	learners' actions, gives them a reason to be engaged with the content rather than just completing content for the sake of completing content. Can also help to humanise the work.

5. Specification

In this section, the requirements and design of the project become more concise. This includes the design and content of all educational content both theoretical and practical and the formal requirements to be evaluated in the future. It should be noted that this was not a linear process, and iterations between this section and section 6 (Realisation) occurred often.

5.1. Interface Prototype

Based on the vision and content outlined in the previous section, a visual prototype was initially created to showcase how the interface may look like. The prototype was created with Justinmind.

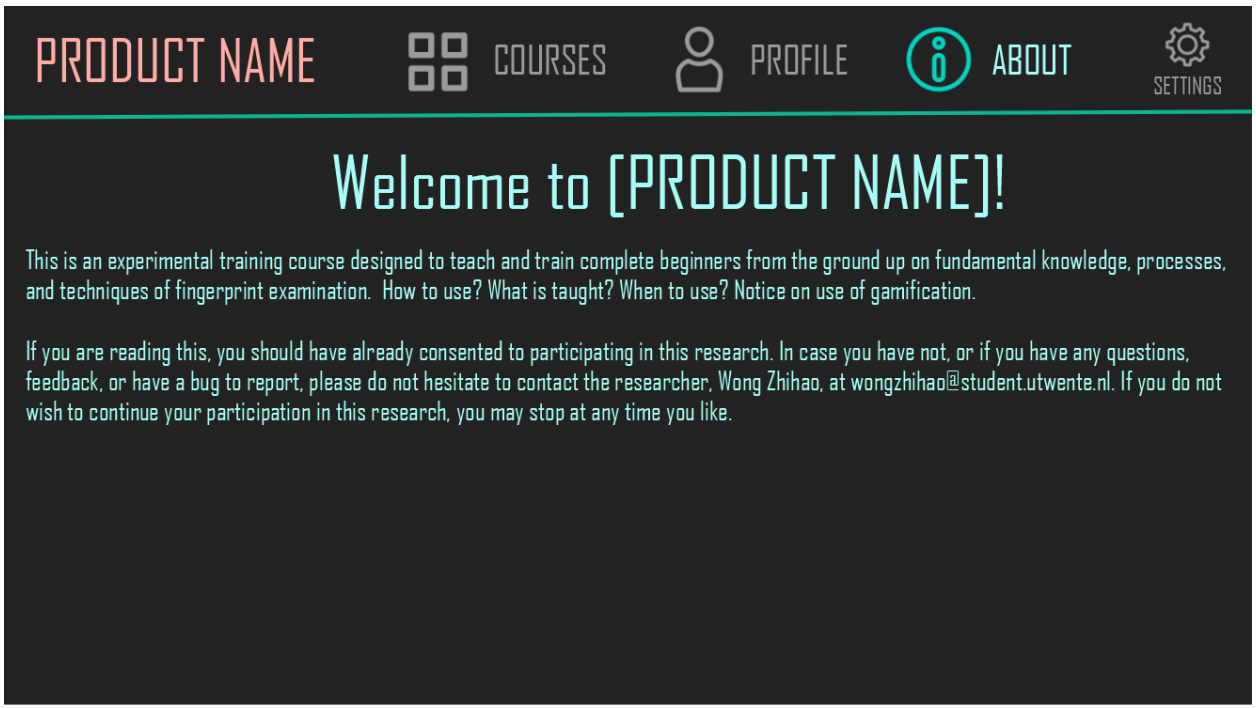


Fig. 9. Main Menu, About Page

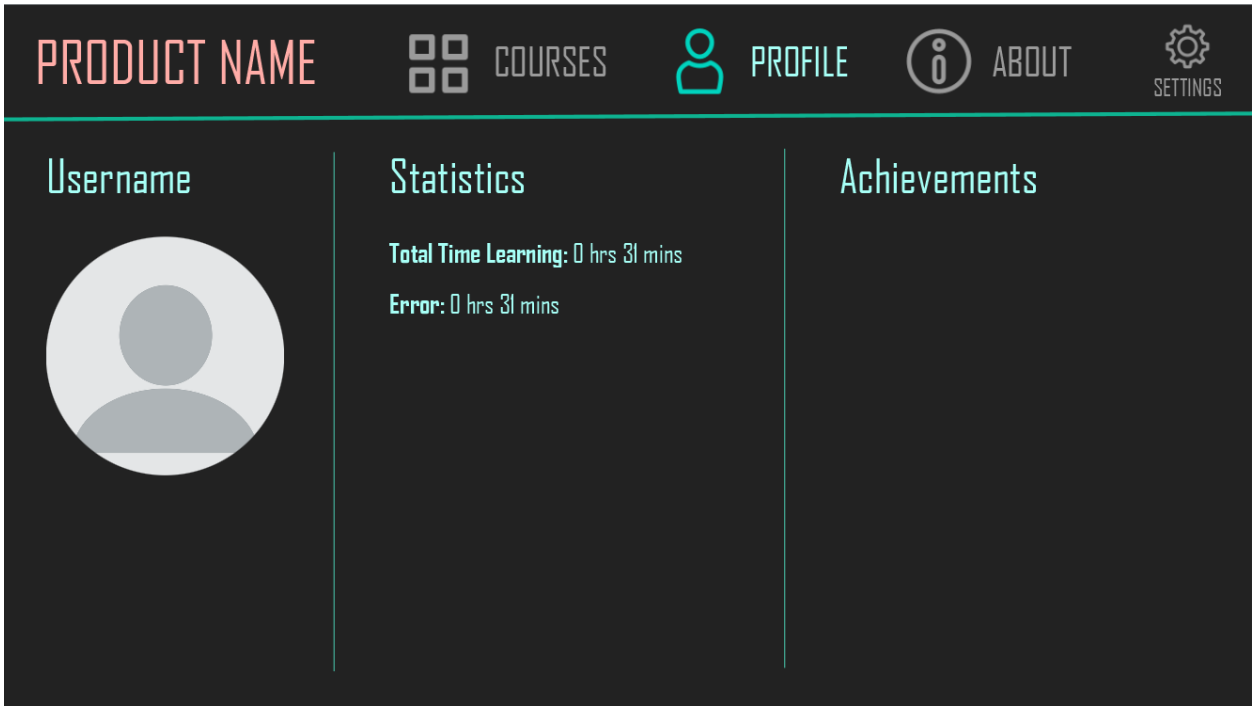


Fig. 10. Main Menu, Profile Page

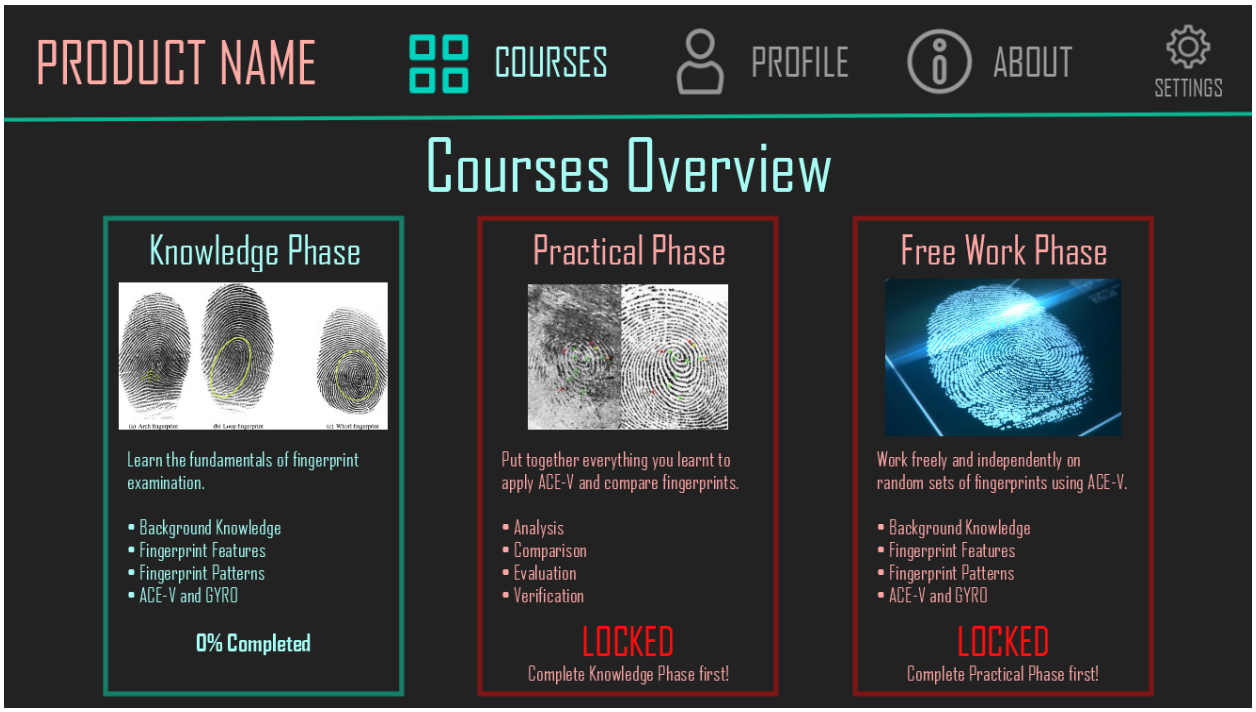


Fig. 11. Main Menu, Courses Page. At this point, the language of distinguishing Programmes and Courses was not finalised yet. The 3 programmes, or phases, are shown here with incomplete text.

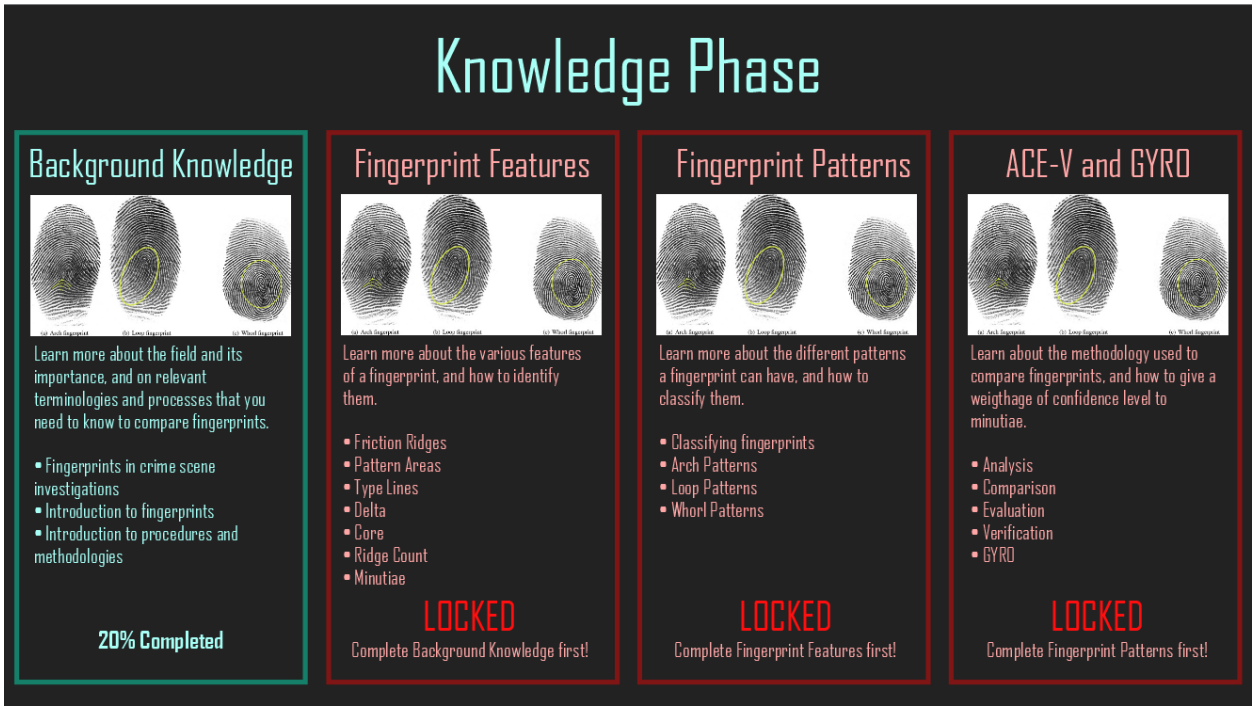


Fig. 12. Main Menu, Courses Page, Knowledge Programme.

Client feedback to the prototype was very positive, and a suggestion was made to immediately move towards creating the actual prototype on whichever platform the application was to be made in instead of continuing development with this visual prototype. As such, the process of the remainder of this section (Specification) was developed concurrently with the development of the application (Realisation). Sections of the application were developed first, and from there, exact specifications and designs could be created and changed on the go rather than writing it out first. This process will be described in greater detail in the next section (Realisation). The remainder of this section will describe the specifications and designs of the application that were created as the application was developed.

5.2. Narrowing the Scope

Originally, there was to be a greater focus on theoretical knowledge by going into specific details and rules of fingerprint patterns, type lines, and various terminologies. Standards on documentation would also be taught at every juncture. However, as development progressed and more research was put into what needed to be taught to achieve this, it was deemed to be unfeasible in such a limited timespan. Such a scope would have entailed having to study and learn such information. Attempting to enforce a certain standard was difficult as well, as there is still no clear consensus on any such standards that would significantly complicate such efforts.

A decision was, therefore, made to mainly focus on building perceptual expertise by spotting and annotating details rather than learning the sciences and rules on how to classify those details. Learners would, however, still have to know how to exactly and precisely annotate such details.

From the existing vision described in section 4, the ideas to enforce standards and implement networking to allow for collaboration were scrapped to focus more on the educational tools and educational content. The ACE-V and GYRO and Free Work programmes were also scrapped. These features would become recommendations for the expansion of this project.

5.3. Courses and Course Flow

The contents of the application will focus on the details that the learner will have to learn to identify and annotate. The courses are as follows and are unlocked in the order they are described. The contents of the lessons and exercises will be described in the later sections.

Course: Theoretical Knowledge

This course only contains 1 lesson and is designed to only provide contextual knowledge and a brief overview of all the types of details the learner will encounter in the application. As a result, this will be the most text-heavy and least interactive course in the application.

Course: Basic Fingerprint Patterns

This course contains 1 lesson and 1 exercise designed to introduce the very basics of fingerprint patterns to the learner and learn to identify the 3 basic fingerprint patterns.

Course: Fingerprint Features

This course is the meat of the application and contains 3 lessons and 3 exercises. Learners will learn about the various level 1 and 2 details in a fingerprint and how to annotate them.

Course: Advanced Fingerprint Patterns

This course was to be the final course of the application but was scrapped due to the potential complications with properly identifying certain fingerprint patterns. This course would have consisted of 3 lessons and 4 exercises and would have built upon the Basic Fingerprint Patterns course and would teach learners how to identify the various sub-patterns of the 3 basic fingerprint patterns.

5.4. Lessons Design and Content

Lessons in the application form the theoretical base of what learners will learn within the application. As mentioned before, the idea is to keep theoretical content at a minimum and only teach what is required to allow learners to identify and annotate details. As such, such content has to be kept as bite-sized and digestible as possible. To do so, lessons would be taught in a slideshow format utilising images as much as possible. This also ensures that text is minimal within the slides. The contents of the various lessons will be described in this section.

Lesson: Background Knowledge

This lesson is part of the first course in the application, Theoretical Knowledge. The main idea of this lesson is to provide background and contextual knowledge on the field and what learners will be learning to give some appreciation on what they will be learning, and then to provide a brief overview of everything they will be learning later on.

Lesson: Basic Fingerprint Patterns

This lesson is part of the second course in the application, Basic Fingerprint Patterns. The lesson will help familiarise learners with the 3 types of fingerprint patterns they will encounter; the loop, whorl, and arch, and provide certain identifying features of each fingerprint pattern. These identifying features include the characteristics of the flow of the friction ridges in each pattern and the number of core and delta that can be found in each pattern.

Lesson: Core

This lesson is part of the third course in the application, Fingerprint Features. The lesson will provide a more concise explanation of what a core is and what constitutes a core compared to the one provided in the first lesson, and give 6 examples of how to precisely identify where the core point is based on the way the ridges form within the core.

Lesson: Delta

This lesson is part of the third course in the application, Fingerprint Features. The lesson will provide a more concise explanation of what a delta is and what constitutes a delta compared to the one provided in the first lesson. Based on the Henry Classification System [24], there are 2 ways a delta can be formed, which will be taught to the learner.

Lesson: Minutiae

This lesson is part of the third course in the application, Fingerprint Features. The lesson explains what a minutia is and will teach learners 4 types of minutiae, bifurcation, ridge ending, dot, and short ridges.

Interactive Features

To provide some interactivity that cannot be achieved with traditional methods and make learning more efficient and effective, 2 interactive features were created; the hover feature and popup explanation feature.

The hover feature allows the learner to move their mouse over an image to reveal annotations on the image that supplements explanations provided in the lesson. This would allow learners to compare the original image against the annotated one, which can be useful when the annotations hide certain details in the print that can make it hard to identify what is happening within the print.

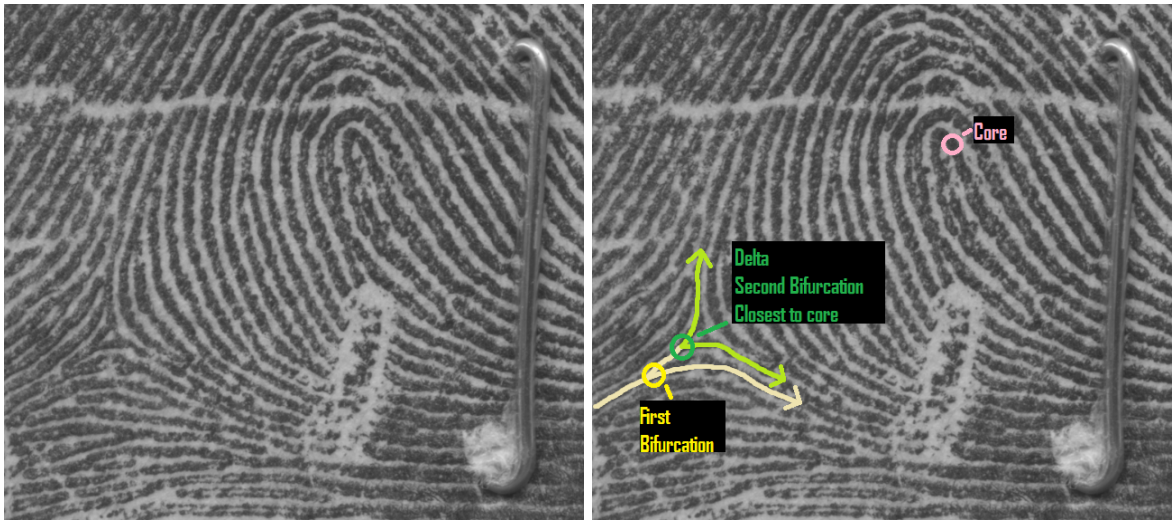


Fig. 13. The left image shows the original image, which will change into the right image when the user moves their mouse over it.

The popup explanation feature allows the learner to click on an image or sections of an image to bring up a further explanation of what they are looking at. This helps to compartmentalise information and not clutter one screen with too much text and explanation.

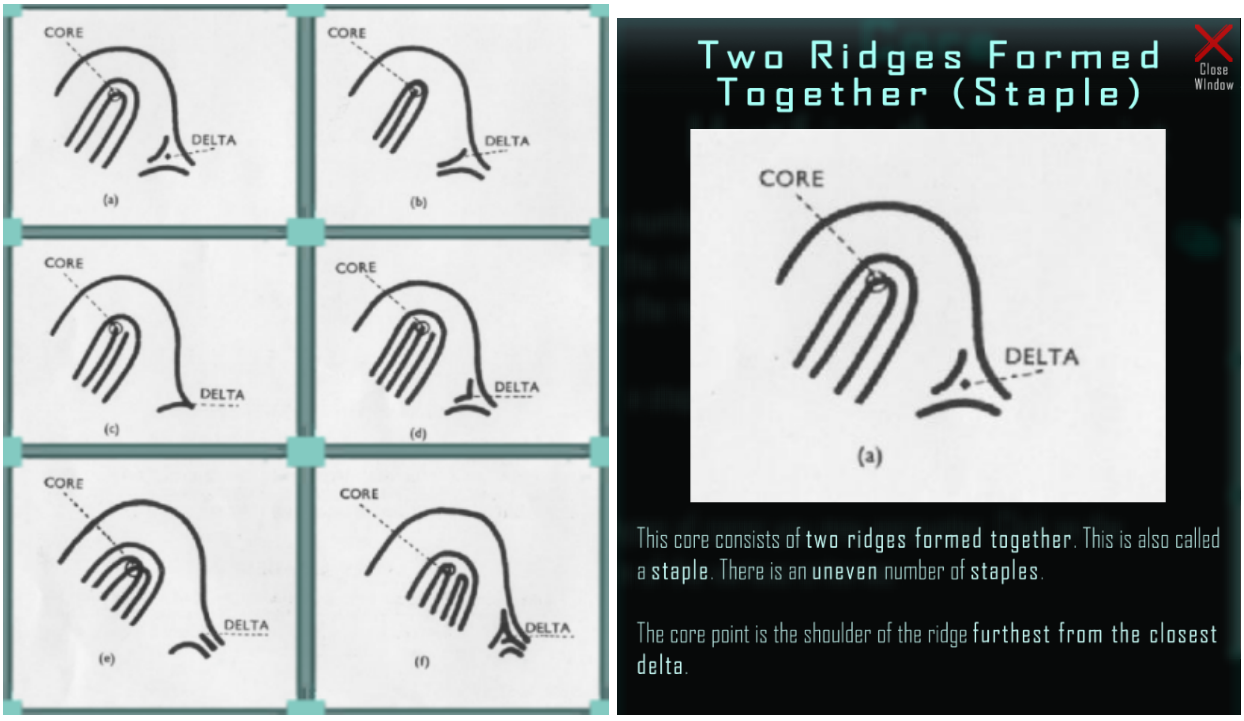


Fig. 14. The left image shows the original image with borders around each clickable portion, the right image is an example of the window that appears when clicking on one of the portions.

Learners can know when an image has either of these interactive features when the appropriate icon is beside the image. The figure below provides a visualisation of what these icons look like.

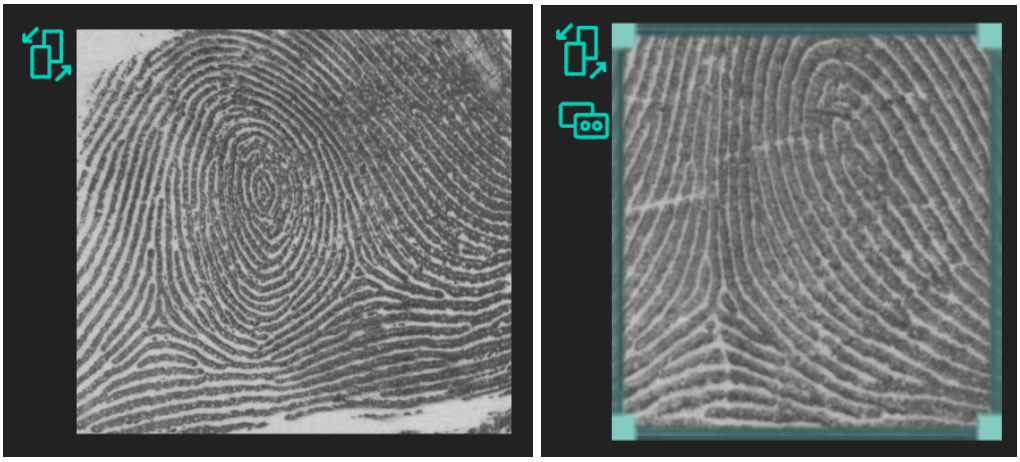


Fig. 15. The left image has an icon on the left indicating that it has the hover feature. The right image has two icons on the left indicating that it has both the hover and the popup explanation features.

5.5. Exercises Design

Exercises provide learners with the opportunity to test their knowledge in practice and are the main interactive component of the application. Exercises can have up to 3 different difficulties, beginner, intermediate, and expert, and learners will have to at least pass the beginner difficulty to unlock additional content and higher difficulty levels. To pass, learners must score at least 50 out of 100 points in the exercise. The contents of the

Exercise: Basic Fingerprint Patterns

This exercise is part of the second course in the application, Basic Fingerprint Patterns, and contains only the beginner difficulty. This exercise tests the knowledge the learner learns from the Basic Fingerprint Patterns lesson. Learners will be shown 20 random fingerprints and will only have to select the type of pattern from a dropdown list.

Beginner Exercise: Only have to identify between loops, whorls, and arches. Will only display all loop patterns, plain whorls and central pocket loops, and plain arches.

Exercises: Core and Delta

Both the core and delta exercises are part of the third course in the application, Fingerprint Features, and both contain all 3 difficulties. These exercises test the knowledge the learner learns from the Core and Delta lessons respectively. Learners will be shown 16 random fingerprints and will have to annotate on the fingerprint the exact location of the core(s) and delta if any.

Learners were originally graded on 2 criteria; their precision and the number of details matched. Precision refers to how far the annotation was from the correct answer. There is also a maximum distance before an answer is not counted as being matched to a detail. This maximum distance

can be altered to adjust the difficulty of the exercise. This would be added with the percentage of matches to give the final grading for this detail.

The last criterion was eventually modified late in the development process to become the learner's accuracy. Accuracy is determined by the percentage of the number of annotated answers from the learner matched to any correct answer, which would determine the maximum percentage of points the learner can gain from the question. This is to prevent learners from spamming annotations in an area and getting a perfect score from that. As such, learners only gain points from their precision and are limited by their accuracy.

Beginner Exercises: The number of cores/delta are provided, and only loop and whorl patterns are tested. References to lesson materials are provided.

Intermediate Exercises: The number of cores/delta are no longer shown, only loop and whorl patterns are tested, and the maximum precision percentage is slightly lower. References to lesson materials are provided.

Expert Exercises: The number of cores/delta are hidden, all patterns are tested, and the maximum precision percentage is significantly lower. References to lesson materials are no longer provided.

Exercises: Minutiae

The minutiae exercise is part of the third course in the application, Fingerprint Features, and contains all 3 difficulties. This exercise tests the knowledge the learner learns from the Minutiae lesson. Learners will be shown 4-8 random fingerprints and will have to annotate on the fingerprint every minutae they can find. The beginner exercise has a different format in the form of an MCQ, where they have to differentiate between the different types of minutiae. Unlike the Core and Delta exercises, learners are only graded on the percentage of minutiae matches in their annotations. Difficulty can be adjusted by increasing the maximum percentage of matches to gain full points for each question.

Beginner Exercises: MCQ questions, learners are shown 40 random images of a minutia and have to identify which of the 4 minutiae types it is that they have learned.

Intermediate Exercises: Annotate 4 fingerprints, only need to match 80% of the minutiae to get maximum points.

Expert Exercises: Annotate 8 fingerprints, must match 100% of the minutiae to get maximum points.

5.6. Gamified Features

This section will describe in more depth the various gamified features implemented in the application, along with their relevance and purpose.

5.6.1. Feedback System

The feedback system provides comprehensive and corrective feedback to learners in between questions to help them understand what they did wrong. Feedback is provided on the above grading criteria of the exercises in section 4.5, and colour coding is provided to further provide information on how the user performed for each specific detail.

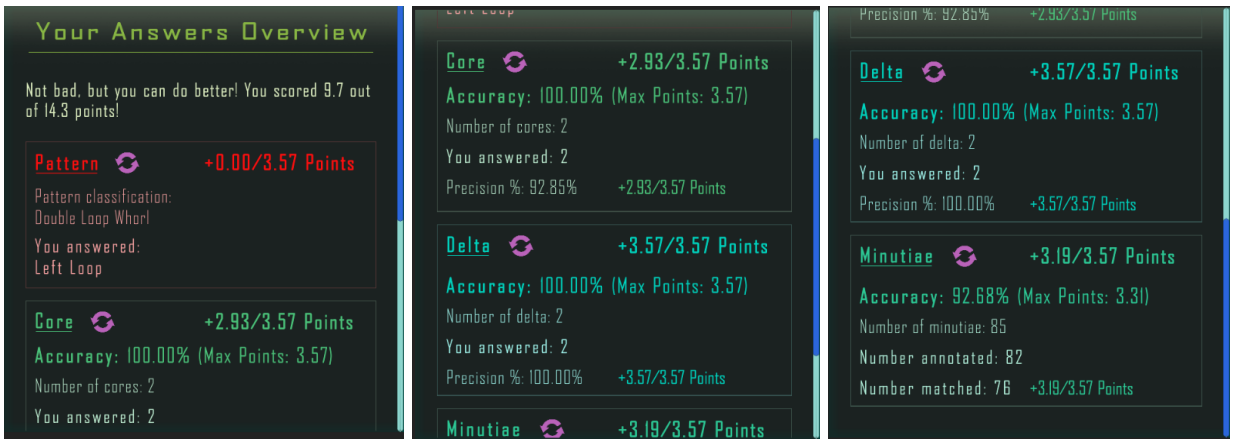


Fig. 16. The feedback provided for every detail.

Later in development, the ability to view the learner's long-term statistics was also added to the feedback system. This can be viewed for each detail by clicking on the pink circle icon.

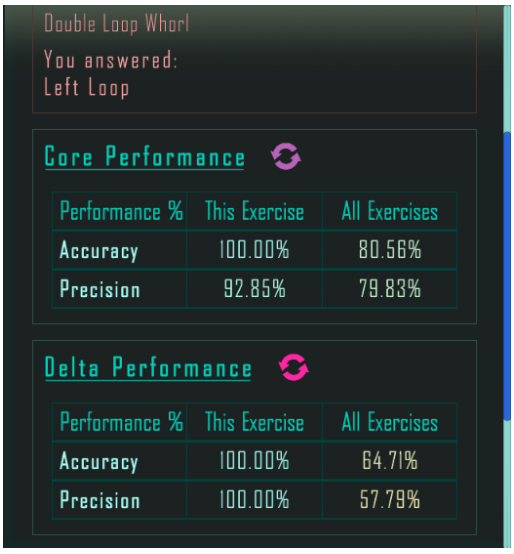


Fig. 17. Viewing statistics of each detail

Learners are also able to view their annotations against the answers on the fingerprint after submitting their answers. Hovering over an annotation will review more information about the grading of that annotation.

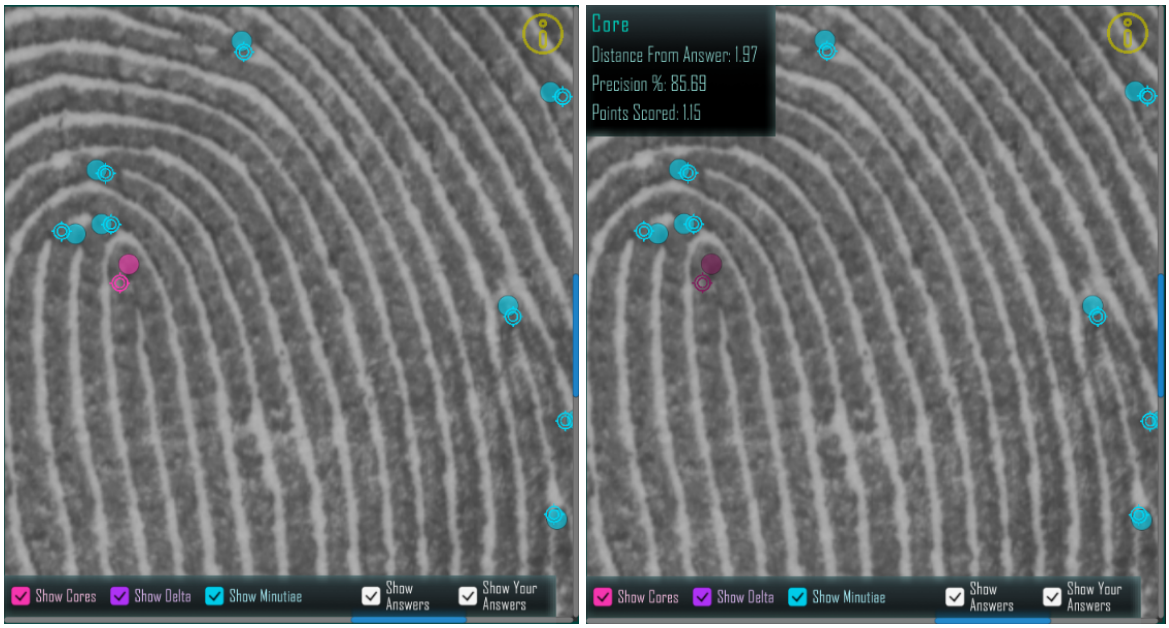


Fig. 18. Correct answers against the learner's annotations

5.6.2. Exercise Difficulties and Rankings

Each exercise can have up to 3 difficulties, beginner, intermediate, and expert difficulties, representing increasing levels of difficulty. This provides the learner with the freedom to challenge themselves with higher difficulties while not locking them from content behind too difficult challenges. Each exercise also provides up to 3 ranks, a bronze (pass), silver (>70 points), and gold (>90 points), which provides learners with a milestone to achieve within each exercise and a form of feedback (stars) for achieving those milestones. Within the course menu, these stars are also visible beside each exercise, which can help the learner feel more accomplished. This can be seen in figure 20.

Fig. 19. Example of 3 difficulties in the Minutiae exercise, with different ranks per exercise.

5.6.3. Progress Bar

Within the course menu, a progress bar is viewable which shows the learner's progression within the course. This progress bar takes into account whether each lesson is completed, and the rankings of each exercise difficulty. This helps the learner identify how far they have progressed within each course.

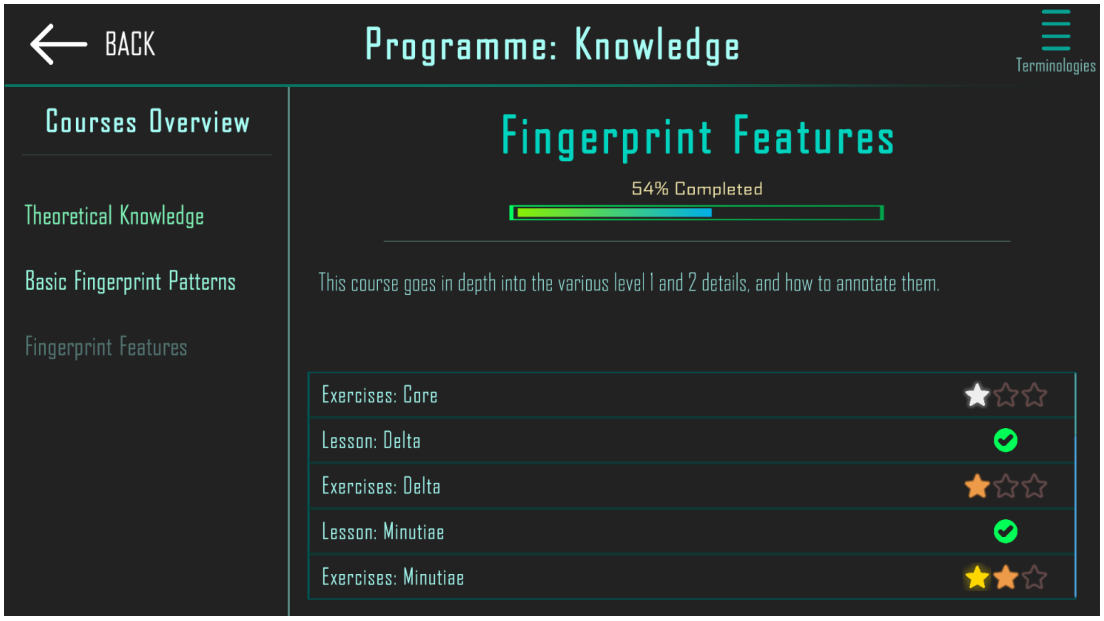


Fig. 20. The course menu of the Fingerprint Features course showing the progress bar, list of lessons and exercises, and the completion of each module.

5.6.4. Achievements

Achievements can be attained for certain milestones such as completing lessons and exercises or annotating a specific number of details. This provides learners with goals to strive for and acknowledges and provides feedback on achieving certain milestones. When an achievement is unlocked, a popup appears at the top of the screen displaying what achievement was unlocked. These achievements can be viewed on the profile page, as described in the next section.

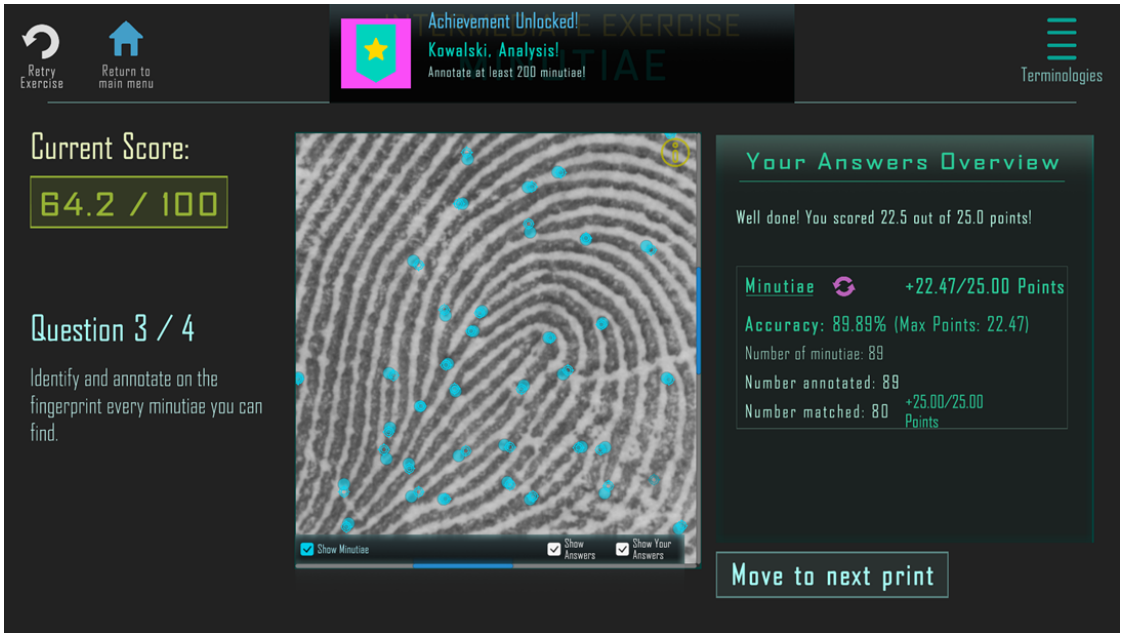


Fig. 21. An achievement popup for annotating at least 200 minutiae

5.6.5. Profile Page

The profile page displays the learner's long-term statistics and all the achievements that have been unlocked and have yet to be unlocked. This provides a hub where the learner can view their performance within the application, and also allows their progress to be stored somewhere, which can provide more meaning to their work.

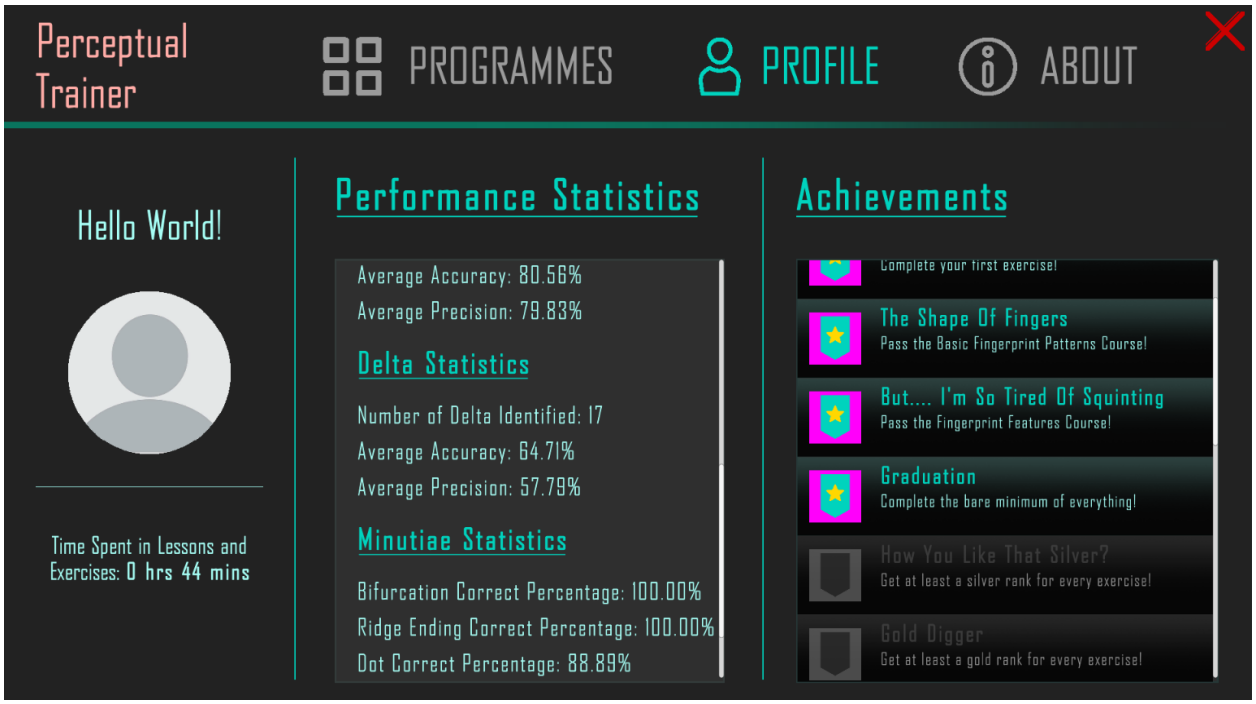


Fig. 22. A user's profile page showing various statistics and achievements.

5.7. Fingerprint Database

A fingerprint database is necessary to display a randomised set of fingerprints for learners to annotate on. Based on the recommendations of the client, the NIST Special Database 300 was requested for and the fingerprints within it will be hand-selected to be part of the database used in the application. The fingerprints used are those with a scanning resolution of 1000 pixels per inch with rolled impressions.

5.8. MoSCoW

Based on several iterations from designing the content of the application, the following MoSCoW requirements were derived:

Must Have:

1. The product must be able to impart fundamental knowledge on fingerprint examination that learners need to have to perform ACE-V.

2. The product must be able to track relevant statistics on learners' performances and behaviours and display this to the learner.
3. The product must have an annotation tool that allows:
    a. Annotation of specific details
    b. Zooming in and out of a fingerprint image
4. The product must be able to compare a learner's annotations against a provided answer to provide automatic grading
5. The product must utilise gamification to attempt to solve the 3 research questions.
6. The product must have a database of annotated prints to allow a minimal number of questions per exercise to be completed.

Should Have:

1. The product should train learners to become proficient with the usage of ACE and GYRO.
2. The database of annotated prints should be sufficiently large to provide a mostly unique randomised set of prints per exercise attempt.
3. The answers that learners will be graded against should be as accurate as possible.

Could Have:

1. The product could provide a platform to freely work with random sets of fingerprints using ACE-V and GYRO.
2. The annotation tool could provide additional quality of life improvements and features such as:
    a. Zooming in towards the mouse cursor
    b. Ridge tracing tool
    c. Free drawing

Won't Have:

1. The product won't attempt to teach in-depth knowledge on fingerprint science and will instead focus on perceptual expertise.
2. The product won't teach documentation and the standards about it.
3. The product won't be networked to connect learners.

6. Realisation

In this section, the realisation and development of the project based on the above requirements and design are described. This section will describe the development of the application in roughly the same order they are introduced as they were developed. It should be noted that this was not a linear process, and iterations between this section and section 5 (Specification) occurred often.

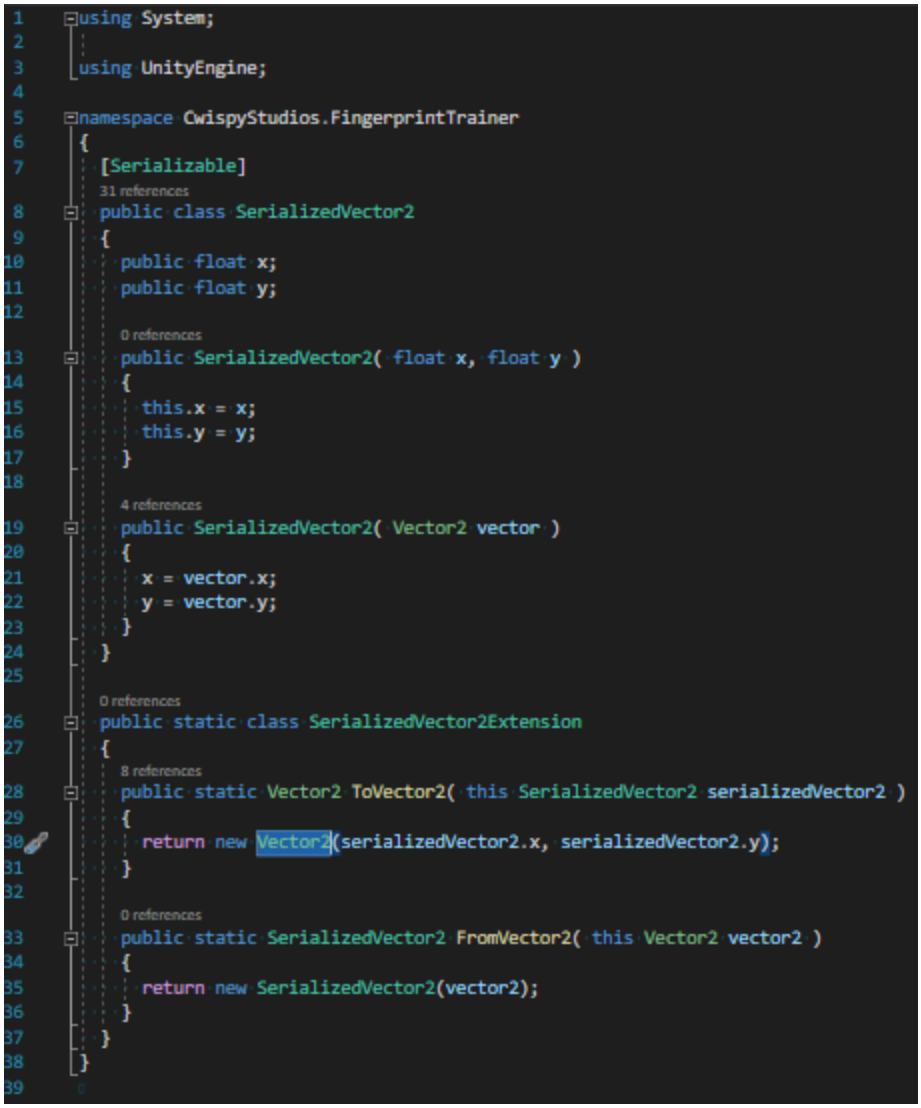
6.1. Platform

The eventual product will be a fully interactive application where learners can consume educational content and perform annotations on a fingerprint image. As such, the development would involve a moderate amount of technical complexity which would require a sufficiently developed platform to build upon. The product would also require rapid prototyping which would be preferable with a platform comfortable with the developer. As such, the application will be built with the Unity Engine.

6.2. Fingerprint Database and I/O Handling

The first step in the development process was being able to perform loading and saving of a fingerprint database, as well as the creation of a database. Fingerprints are stored within the Resources folder of the Unity project to allow for easy I/O handling through Unity's API. The details of the fingerprint, such as its pattern type and location of its core, delta, and minutiae, can be saved as a JSON in the same location with the same name as the image, allowing for easy identification of which fingerprint the JSON is providing information for. From there, every fingerprint image can be easily loaded with the Resources.LoadAll function by specifying a typeof(Sprite) as its second argument. Likewise, every JSON containing information about its fingerprint can be loaded with the same function by specifying a typeof(TextAsset) as its second argument.

Saving information can be done easily by reading the various states in a scene specifying the information to be saved and saving it in a class with the Serializable property. This class is called FingerprintDetails. More information about this scene and the developer tool can be found in the next section. This class contains all the information that will be saved in the JSON. Saving coordinates requires an additional step as the Vector2 struct is not a serializable struct, and a separate serializable class had to be created to properly serialise coordinates.



```
using System;

using UnityEngine;

namespace CwispyStudios.FingerprintTrainer
{
    [Serializable]
    31 references
    public class SerializedVector2
    {
        public float x;
        public float y;

        0 references
        public SerializedVector2( float x, float y )
        {
            this.x = x;
            this.y = y;
        }

        4 references
        public SerializedVector2( Vector2 vector )
        {
            x = vector.x;
            y = vector.y;
        }
    }

    0 references
    public static class SerializedVector2Extension
    {
        8 references
        public static Vector2 ToVector2( this SerializedVector2 serializedVector2 )
        {
            return new Vector2(serializedVector2.x, serializedVector2.y);
        }

        0 references
        public static SerializedVector2 FromVector2( this Vector2 vector2 )
        {
            return new SerializedVector2(vector2);
        }
    }
}
```

Fig. 23. The SerializedVector2 class can be serialized in a JSON in place of a Vector2 struct.

From there, the FingerprintDetails class can be converted into a JSON through the use of Unity's JsonUtility function, ToJson, and saved into the relevant folder with the use of System.IO's FileStream and StreamWriter classes. When loading the fingerprint database, it is then stored as a dictionary, with the key being the pattern type (see sections 5.3 and 5.4) and the value being the list of fingerprint details belonging to that pattern type.

```
public void OnSaveJSON()
{
    Detail[] allMinutiae = annotater.GetComponentsInChildren<Detail>();
    Sprite fingerprintSprite = annotater.GetComponent<Image>().sprite;

    FingerprintDetails fingerprintDetails = new FingerprintDetails();
    fingerprintDetails.FingerprintSpriteName = fingerprintSprite.name;
    if (int.TryParse(ridgeCountInputField.text, out int ridgeCount)) fingerprintDetails.RidgeCount = ridgeCount;
    fingerprintDetails.PatternType = (PatternType)(1 << patternTypeDropdownList.value);
    fingerprintDetails.DetailsScale = detailScaleSlider.value;
    fingerprintDetails.CanUseForCore = canUseForCoreToggle.isOn;
    fingerprintDetails.CanUseForDelta = canUseForDeltaToggle.isOn;

    foreach (Detail minutiae in allMinutiae)
    {
        switch (minutiae.DetailType)
        {
            case DetailType.Core:
                fingerprintDetails.CoreCoordinates.Add(new SerializedVector2(minutiae.GetComponent<RectTransform>().anchoredPosition));
                break;

            case DetailType.Delta:
                fingerprintDetails.DeltaCoordinates.Add(new SerializedVector2(minutiae.GetComponent<RectTransform>().anchoredPosition));
                break;

            case DetailType.Minutiae:
                fingerprintDetails.MinutiaeCoordinates.Add(new SerializedVector2(minutiae.GetComponent<RectTransform>().anchoredPosition));
                break;
        }
    }
```

Fig. 24. The code to save various information in the serializable class.

6.3. Developer Tool and Annotation Tool

To test out if the I/O is working, a scene had to be created that would allow for such information to be saved. As such, a developer tool was created to perform such actions. This developer tool would therefore be used to create the JSON details and annotate the answer sheets used in the exercises.

A rough annotation tool was first created to perform such actions to test out the I/O as can be seen in figure 24. This tool allowed the annotation of cores and delta, the annotation of the exact type of minutiae, an erase tool to erase annotations on a print, the classification of what pattern type a print is, a details scale to scale the size of annotations to the average size of friction ridges in the print, and the ability to load a fingerprint and save the details in a JSON. This annotation tool would go on to be used in the actual exercises that learners will interact with.

Fig. 25. The developer tool in its early stages. After loading an image, the print would be visible in the white box.

When annotating, a prefab is created as a child of the fingerprint image at the location of the mouse click. This location can be easily found by implementing the IPointerClickHandler interface. This would implement the OnPointerClickFunction, with the PointerEventData argument providing the position of the event. Using the ScreenPointToLocalPointInRectangle function in the RectTransformUtility class, the local position of the click relative to the fingerprint image can be found. Erasing an annotation can also be done by retrieving the RaycastResult object from the event data and destroying it.

```
1 reference
public void OnPointerClick( PointerEventData eventData )
{
    if (originalImage.sprite == null) return;

    if (currentSelectedDetail != 0)
    {
        RectTransformUtility.ScreenPointToLocalPointInRectangle(imageTransform, eventData.position, eventData.pressEventCamera, out Vector2 point);

        CreateDetailAtPoint(currentSelectedDetail, point);
    }

    else if (isErasing)
    {
        Detail clickedUiElement = eventData.pointerPressRaycast.gameObject.GetComponent<Detail>();

        if (clickedUiElement != null)
        {
            annotatedDetails[clickedUiElement.DetailType].Remove(clickedUiElement.GetComponent<Detail>());
            Destroy(clickedUiElement.gameObject);
        }
    }
}
```

Fig. 26. The code to create or erase an annotation object when clicking on the fingerprint image.

Parenting the annotations to the fingerprint image ensured annotations would have local positions anchored to the parent image. The coordinates of these annotations could then be stored

by saving their anchoredPosition within the RectTransform component. When reading these coordinates, the prefabs can be instantiated using those coordinates as their localPosition and they would end up at the same spot. As can be seen in figure 18, the annotations of the correct answer are also created the same way from a prefab with a different sprite. These prefabs would also hold the detail type it is, which allows differentiating between every annotation prefab.

The annotation tool also allows for zooming in and out of the image. This is easily done by adjusting the scale of the image object. As the annotations are child objects of the image, there is no need to manually scale these objects other than when creating annotations while the image is zoomed in.

To retrieve information about a fingerprint and store it as a JSON, a script only needs the reference to the UI objects in figures 25 and 28 and be able to read their values. Retrieving the annotations in an image can be simply done through the use of GetComponentsInChildren on the fingerprint image and specifying a unique component found on the annotation prefab.

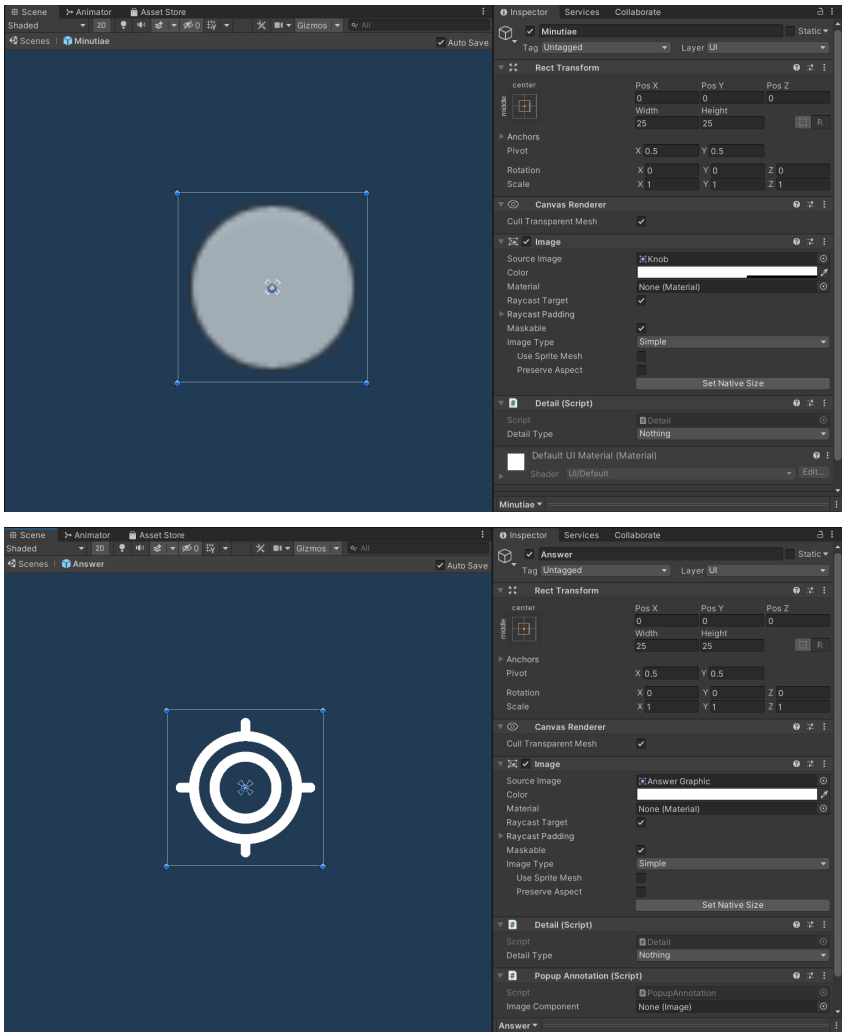


Fig. 27. The prefabs of a minutiae annotation (top image) and an answer annotation (bottom image)

As development continued, more features were added, refined, or changed depending on the requirements and design of the educational content. The final version of the developer tool can be seen in figure 28.

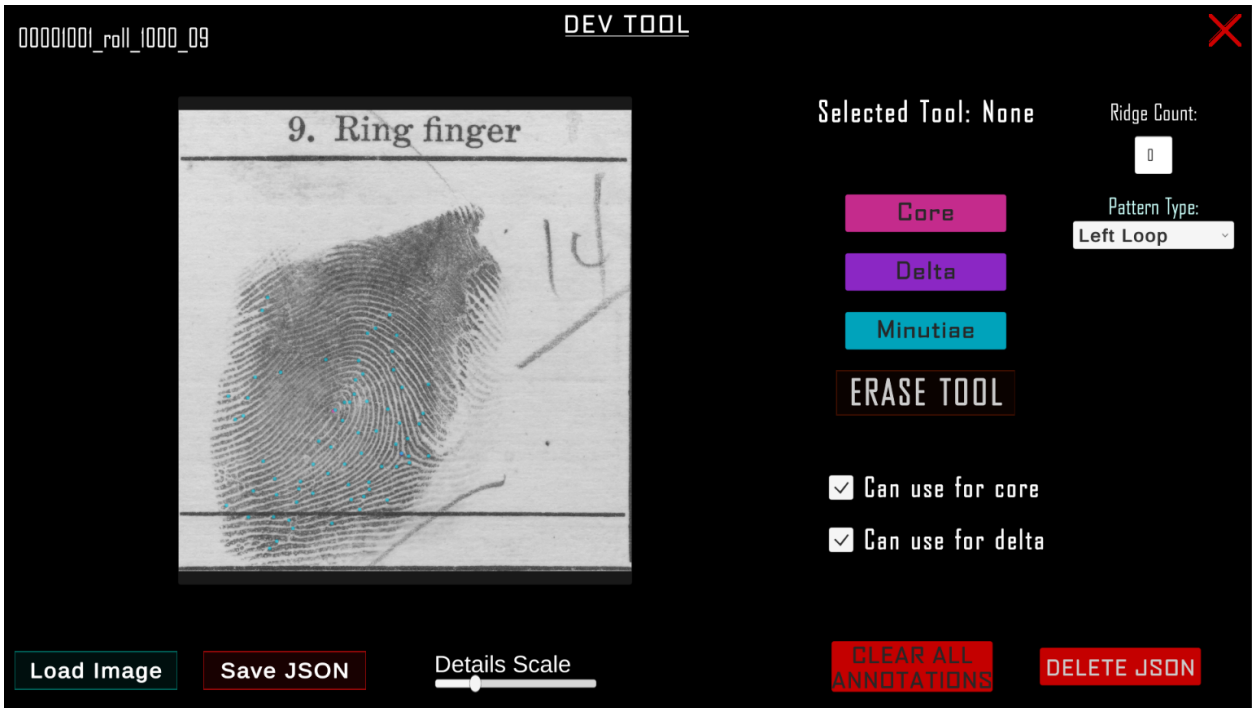


Fig. 28. The final version of the developer tool.

Specifying minutiae type became unnecessary and was combined into just a single minutiae annotation button. A ridge count option was also added, but as ridge counting ended up being scrapped from the final product, it became redundant. An option was added to allow the print to be used for core or delta exercises. This was so that fingerprints without a core or delta could also be tested, and fingerprints, where I was unsure of where to annotate the core or delta, could be exempted from testing so that it does not appear as a print without a core or delta. Additional features were added to clear all annotations in a print and to permanently delete the JSON of a fingerprint.

To assist with organising the fingerprints, a cataloguing tool was created to easily show if a fingerprint has been annotated and what features have been annotated, as well as the number of patterns in the database. This tool can be seen in figure 29.

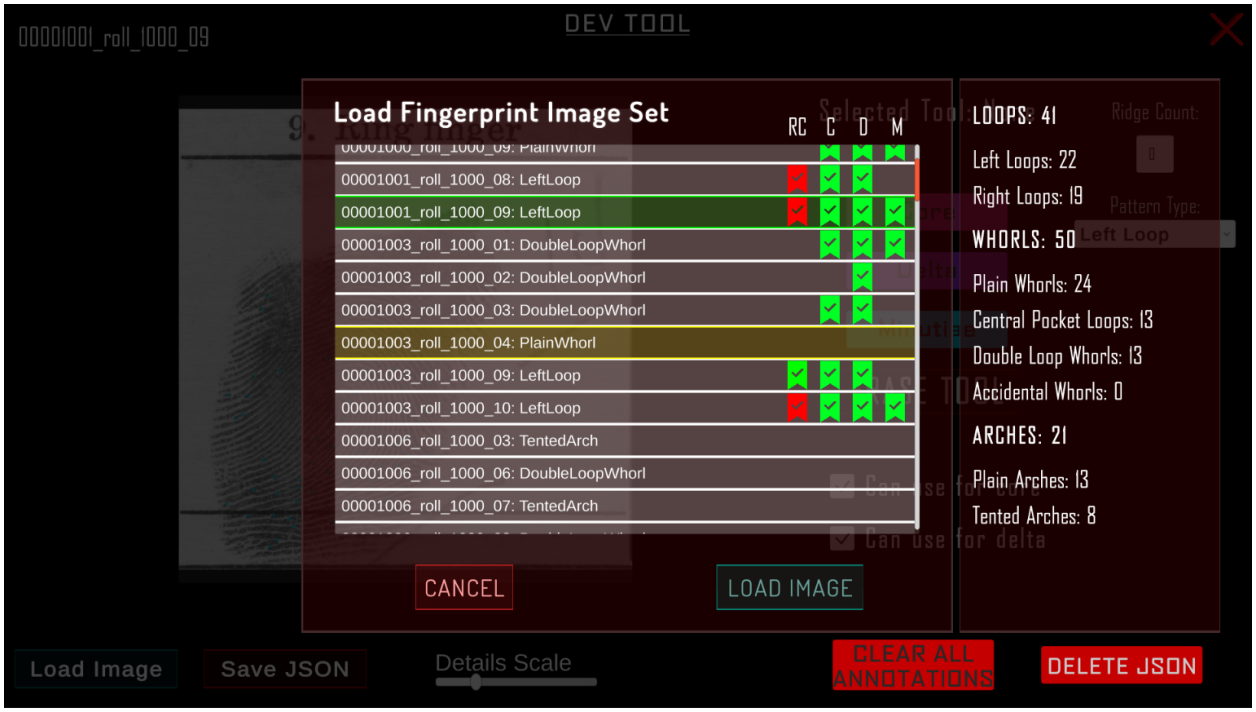


Fig. 29. The organisation tool for the fingerprints database can be brought up by clicking on the Load Image button.

6.4. Lessons and Exercises Slides System

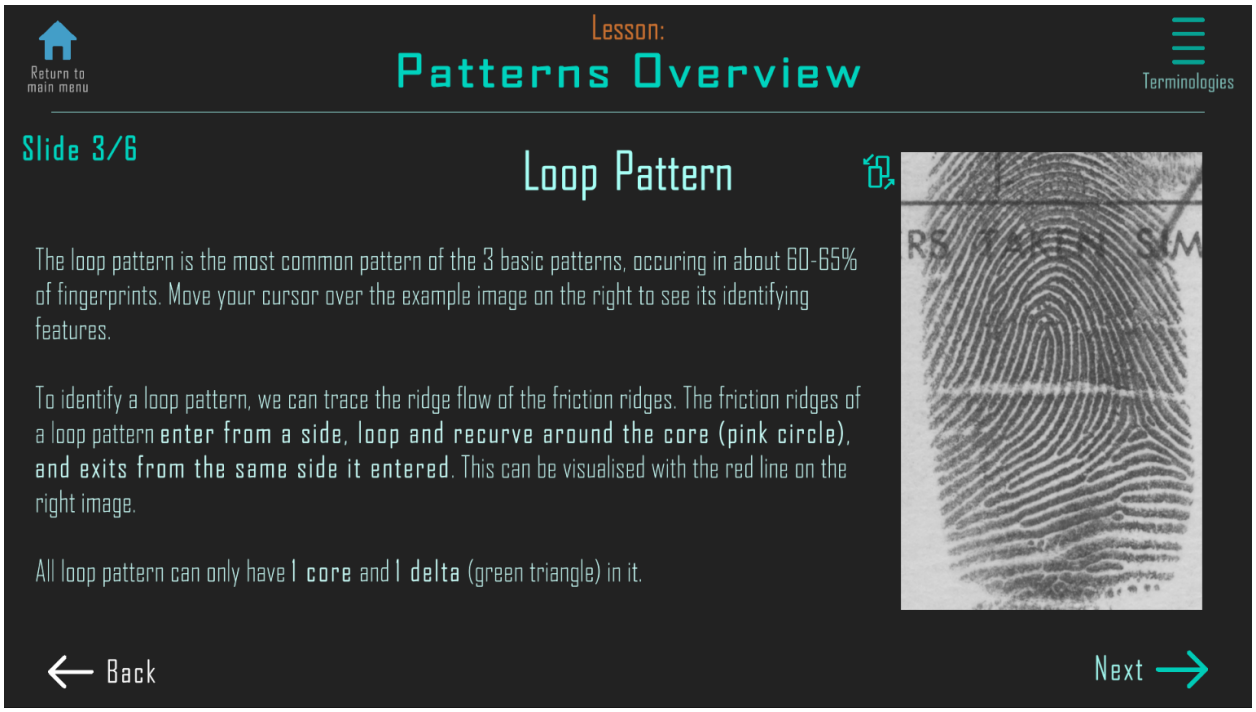


Fig. 30. An example of what a slide in a lesson would look like.

As mentioned in an earlier section, lessons will follow a slideshow format. To achieve this, different panels were created for each slide with all the content such as the text and images being

child objects of the panel. A script can then be created to hold all of these panels in the order they should be viewed in. From there, back and next buttons can be created that when clicked, call a function within the script to display the previous or next slide. Based on the slide number, the next or back button can also be easily hidden or shown.

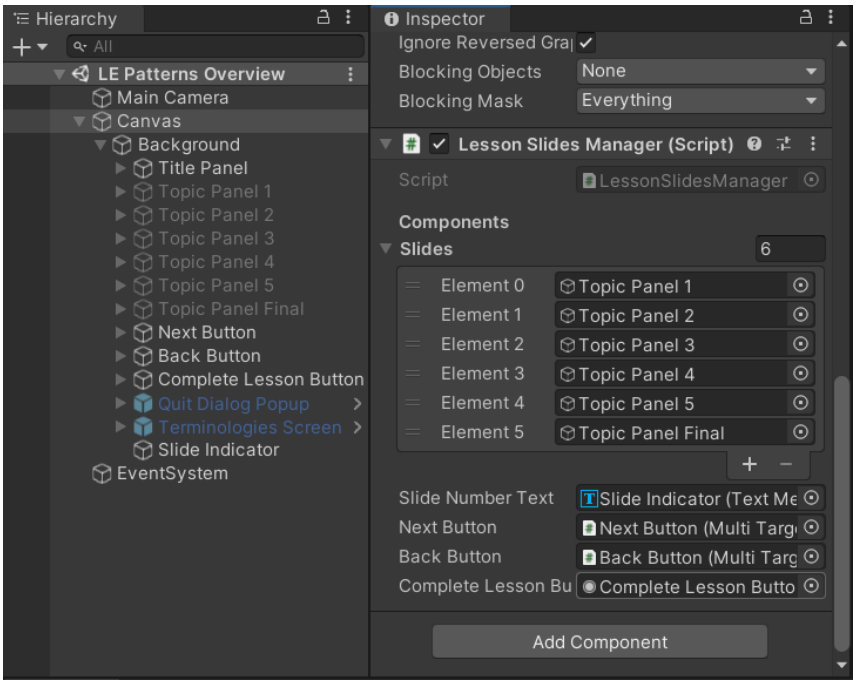


Fig. 31. An example of what a slide in a lesson would look like.

Exercises also follow the same format but will always only have 3 slides; the introduction slide displaying information about the exercise, the exercise slide holding the interactive contents of the slide, and the results slide showing the results of the exercise.

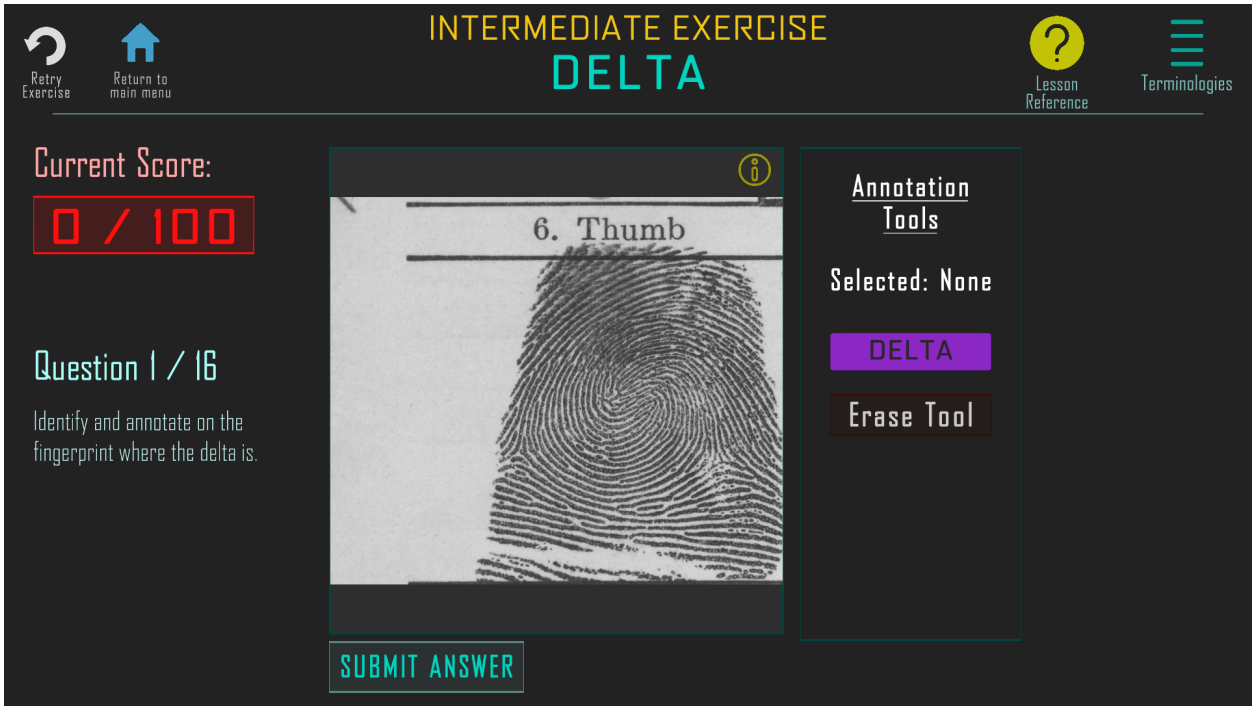


Fig. 32. An example of what the questions of an exercise would look like.

Within the exercise slide object is an object with the ExerciseHandler script that handles all the contents of the exercises, from the number of questions to the difficulty level, to the types of details tested and therefore the nature of the questions and grading. The tested detail types are implemented as an enum flag, allowing for multiple selections to be made. Based on these selections, the ExerciseHandler shows the relevant annotation tools to be made available in the exercise. Pattern types are also implemented as an enum flag, and along with the selected detail types, this allows the filtering of pattern types and fingerprints with the correct information to be selected from the fingerprint database to be tested.

The ExerciseHandler also keeps track of the number of questions and the question the user is at. At every new question, it will pick a random fingerprint from the filtered fingerprint database to be shown, and its corresponding FingerprintDetails class is stored as the answer sheet to be compared against.

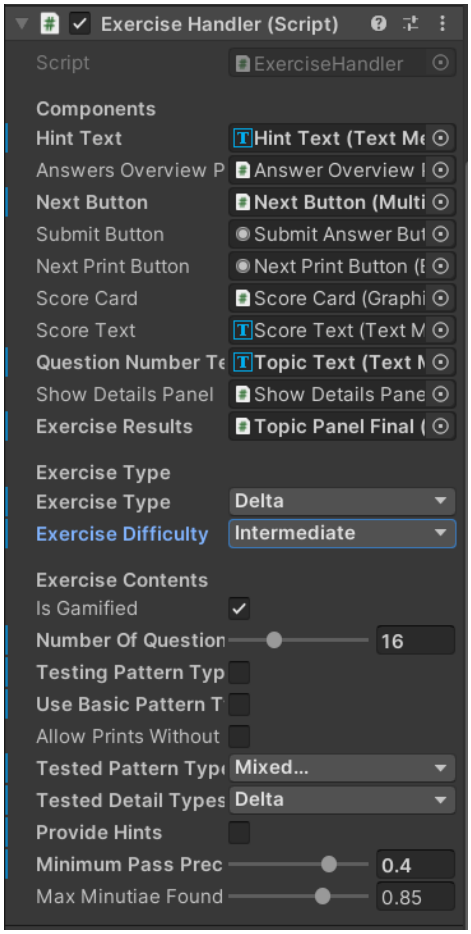


Fig. 33. The ExerciseHandler script

6.5. Automated Grading System

With both the answer sheet and the location of all of the user's annotations on the print, grading can be performed. With the fingerprint pattern, it is simply checking for a match between the enum values of the FingerprintDetails class and the value selected from the dropdown list. Points awarded are split equally between the number of details tested.

Grading annotations is much more complex. With the grading of the core and delta or the level 1 details, there are 2 criteria to keep track of; accuracy, which is the percentage of annotations matched to answer, and precision, which is the average distance of the answers between its matches. The answer annotations are first looped through and compared against every of the user's annotations, checking if each of the user's annotations is within a maximum distance from the correct answer. If it is, it matches them together, removes them from the list of user's answers, and determines the precision.

A precision of 100% is roughly the distance of the radius of the annotation prefab and therefore counts as a full score. This is called the perfectPrecisionMargin. Further from that, the precision drops linearly from 100% to 0%, which is at the maximum distance. This maximum distance by

default is about 7 times the perfectPrecisionMarign. The difficulty of the exercise can be made higher by dropping this maximum distance, forcing users to be more precise with their annotations. If there are no matches, then the precision is 0% by default. The precision percentage is then average across all matches to provide the final score. The accuracy can be easily determined by the number of matches against the maximum of the number of user annotations and number of answers.

For the grading of minutiae, the algorithm to match details is a little more complex, since we want to match the answer closest to each user's annotations together rather than the first one each one finds, which would lead to many incorrect matches. To accomplish this, the list of the user's annotations are looped through, and an ordered list by distance to each answer within an acceptable maximum distance (about the radius of the prefab multiplied by 4) is created for each annotation. If this list is populated, it is added to a dictionary of every detail as the key with that list as its value. Otherwise, that annotation is considered unmatched and will award no points and contribute to lower accuracy.

Following this, the details within the dictionary are looped through to find the closest matching distance between a user's annotation with an answer and matches them together. This process continues until there are no more annotations to be matched together. From this, the number of matches can be easily found, and the score is provided by the percentage of matches. The difficulty can be lowered by decreasing the percentage of matches required to get a full score.

6.6. Feedback System

The grading from the ExerciseHandler can then be easily passed to a user interface to display the average accuracy, precision, and the number of details matched. Based on the results of each detail type, the colour of the user interface can also be changed. More information about this can be found in section 5.7. Later in development, tracking of long term statistics was done on the learner's performance, allowing this to also be shown.

In addition, the answers can also be displayed on the same print to provide a visualisation of what the learner did right or wrong. These answers are also prefabs that are created and linked with the user's annotations during grading when they are matched together. Otherwise, they can remain unlinked as well. Hovering over each annotation would bring up a popup at the corner of the print displaying the grading information of that annotation. This is achieved through the use of the interface IPointerEnterHandler to feed information to the popup and display it.

6.7. Graphics Gradient

As can be seen in figure 34, the colour of many different elements can be changed to reflect the performance of each of those categories. The colour in this instance ranges from red (0% points) to yellow (50% points) to turquoise (100% points). For each of these colours, there is also a

darker and lighter colour. Note that a blur effect in the user interface is also present which holds a coloured material that cannot be changed in the same manner as the other graphic types, where the colour can be directly accessed and changed.

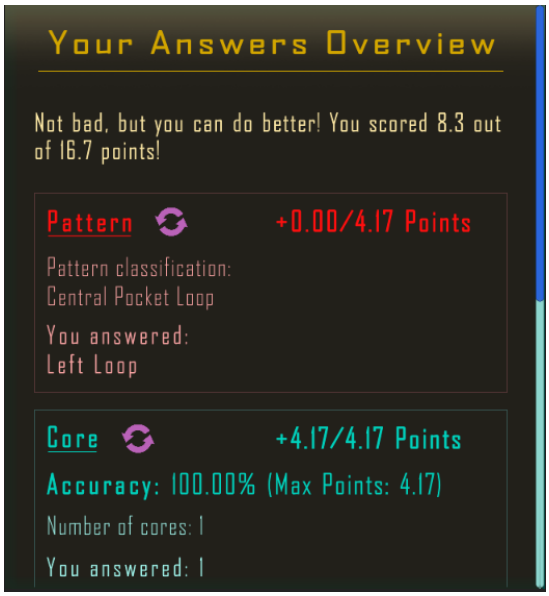


Fig. 34. Example of how the colour of each user interface changes based on the performance of that category.

To easily achieve this without hardcoding the behaviour of everything, a scriptable object was created to hold the information of these colours. This is the GraphicsGradientColourScriptableObject which provides 3 different gradient points to lerp between. At each point, there are 3 types of graphics type, a bold colour (the headers), a light colour (normal text), and a material for the blur.

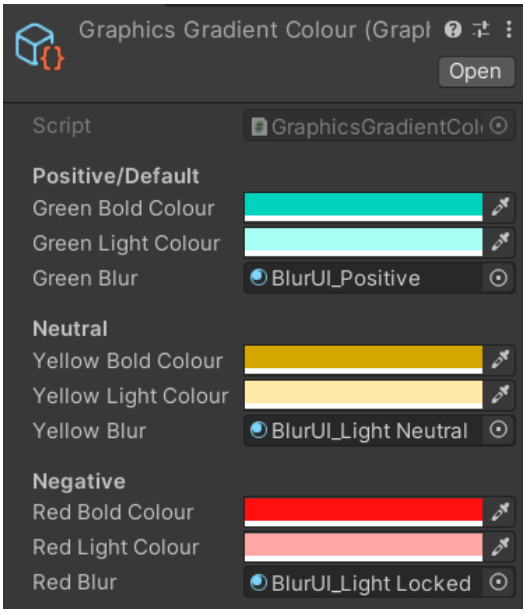


Fig. 35. The colours used to change the user interface of the feedback system.

```
using UnityEngine;

namespace CwispyStudios.FingerprintTrainer.UI
{
    [CreateAssetMenu(fileName = "GraphicsGradientColour", menuName = "Scriptable Objects/Graphics Gradient Colour", order = 0)]
    Unity Script | 1 reference
    public class GraphicsGradientColourScriptableObject : ScriptableObject
    {
        [Header("Positive/Default")]
        public Color GreenBoldColour;
        public Color GreenLightColour;
        public Material GreenBlur;

        [Header("Neutral")]
        public Color YellowBoldColour;
        public Color YellowLightColour;
        public Material YellowBlur;

        [Header("Negative")]
        public Color RedBoldColour;
        public Color RedLightColour;
        public Material RedBlur;
    }
}
```

Fig. 36. The code of the GraphicsGradientColourScriptableObject.

From there, two classes are essential, the GraphicsGradientParent and the GraphicsGradient. The role of the GraphicsGradient is simple, it should be placed on a graphics element whose colour should be changed, and a GraphicsType enum can be specified for whether it is a bold, light, or blur (material) element. The GraphicsGradient should then be a child object of a GraphicsGradientParent. The role of this class is to collect all the GraphicsGradient child objects while excluding those that belong to another GraphicsGradientParent, and lerp between the 3 gradient points based on a provided value. A public function is then accessible where such a value, for example, the grade, can be provided, and the colours of every element will be automatically changed. The code for this function is viewable in figure 37.

```
72      /// <summary>
73      /// Sets every graphics gradient object to the specified value. 0 is negative, 1 is neutral, 2 is positive
74      /// </summary>
        40 references
75      public void SetGraphicsToValue( float value )
76      {
77          if (!isInitialised) Initialise();
78
79          Color boldColour = value <= 1f ? Color.Lerp(gradientColours.RedBoldColour, gradientColours.YellowBoldColour, value)
80              : Color.Lerp(gradientColours.YellowBoldColour, gradientColours.GreenBoldColour, value - 1f);
81          Color lightColour = value <= 1f ? Color.Lerp(gradientColours.RedLightColour, gradientColours.YellowLightColour, value)
82              : Color.Lerp(gradientColours.YellowLightColour, gradientColours.GreenLightColour, value - 1f);
83
84          foreach (GraphicsGradient graphicsGradient in boldGraphics)
85          {
86              graphicsGradient.AdjustGraphicsGradientColour(boldColour);
87          }
88
89          foreach (GraphicsGradient graphicsGradient in lightGraphics)
90          {
91              graphicsGradient.AdjustGraphicsGradientColour(lightColour);
92          }
93
94          Material startMaterial = value <= 1f ? gradientColours.RedBlur : gradientColours.YellowBlur;
95          Material endMaterial = value <= 1f ? gradientColours.YellowBlur : gradientColours.GreenBlur;
96          float t = value <= 1f ? value : value - 1f;
97
98          foreach (GraphicsGradient graphicsGradient in materialGraphics)
99          {
100             graphicsGradient.AdjustGraphicsGradientMaterial(startMaterial, endMaterial, value);
101         }
102     }
103
```

Fig. 37. The code to adjust the colour of the GraphicsGradient child objects of the GraphicsGradientParent.

While this was originally only used for the feedback system, it was found to be useful for other UI elements where the colour had to be lerped between multiple values. This includes the star ranking colours (from bronze to silver to gold), and the achievement colours (locked and unlocked). As such, it became clear that the script should be changed to take in a variable number of gradient values to be more flexible with its usage. This refactor, however, has not been performed yet.

6.8. Loading and Save User Data

The process of saving data is relatively simple and very similar to how the JSON of a fingerprint would be saved in section 6.3. A serializable class SaveData as can be seen in figure 38 is also created to store all of the user's data, and from there, it can be loaded and saved using the BinaryFormatter and FileStream classes in the Application.persistentDataPath file path.

```
public class SaveData
{
    // Seconds
    public float TotalTimeSpentInLessonsAndExercises;

    // Module completion
    public List<bool> LessonsCompleted;
    public List<List<ExerciseResultsData>> ExercisesCompletion;

    public int NumberBronzeStars;
    public int NumberSilverStars;
    public int NumberGoldStars;

    // Pattern accuracy
    public CategoryStatistics LoopsStatistics;
    public CategoryStatistics WhorlsStatistics;
    public CategoryStatistics ArchesStatistics;

    // Annotation statistics for core, delta, and minutiae
    public AnnotationStatistics CoreStatistics;
    public AnnotationStatistics DeltaStatistics;
    public AnnotationStatistics MinutiaeStatistics;

    // Minutiae MCQ accuracy
    public CategoryStatistics BifurcationStatistics;
    public CategoryStatistics RidgeEndingStatistics;
    public CategoryStatistics DotStatistics;
    public CategoryStatistics ShortRidgeStatistics;

    public float CompletionPerc;

    public bool ProgrammesPopupEncountered;
    public bool CoursesPopupEncountered;
    public bool LessonsPopupEncountered;
    public bool HoverImageEncountered;
    public bool PopupImageEncountered;

    // Achievements
    public List<bool> AchievementsCompleted;

```

Fig. 38. The code for the serializable class that saves the user's data.

A singleton object DontDestroyOnLoad UserProfile class handles this loading and saving which is persistent throughout the application. As a singleton object, other classes can easily retrieve this class to save and change new data. This is done by providing public functions that allow the modification of the SaveData class rather than allowing other classes to directly access the SaveData class. Through these public functions, it can also invoke certain Actions which the achievement system can subscribe to.

6.9. Achievement System

The achievement system consists of several classes and scriptable objects. Most important is the AchievementManager class which belongs on the same object as the UserProfile class, and is therefore also persistent throughout the application. The AchievementManager contains multiple AchievementScriptableObject parent classes, which is inherited from 3 other scriptable objects.

These scriptable objects specify from the parent AchievementScriptableObject the AchievementType, which is an enum of every unlockable achievement, its name, description, and image of the achievement.

From there, its 3 inherited classes specify the type of achievement, and therefore, the action that must be performed to unlock that specific type of achievement. These are the ModuleAchievementScriptableObject, which is unlocked through completing a lesson or exercise, the RankAchievementScriptableObject, which is unlocked through attaining a specified number of ranks, and the DetailAchievementScriptableObject, which is unlocked through annotating and matching a specified number of a specific type of detail.

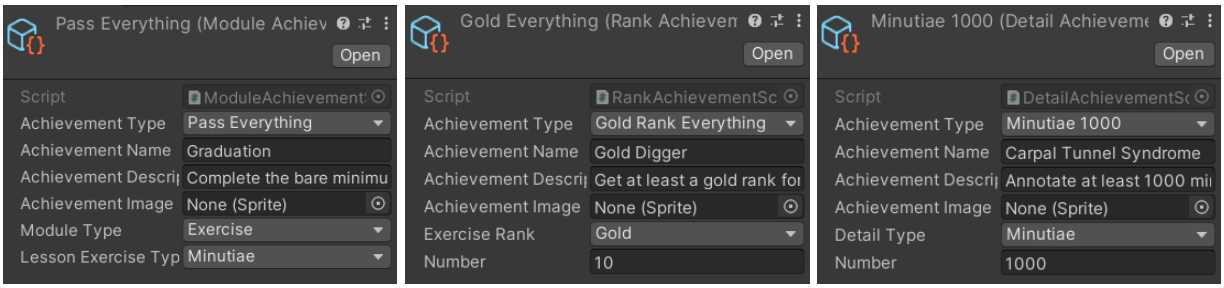


Fig. 39. An example of each of the achievement scriptable objects. All of them have no Achievement Image which would default them to using a default image.

The AchievementManager can then subscribe to the relevant Actions available in the UserProfile to track if the achievement action has been completed, and if so, if that achievement has not already been unlocked, which will then unlock that specific achievement. To create the achievement popup as seen in figure 21, an AchievementNotificationPanel prefab is instantiated in every scene to hold every achievement that pops up within the scene as they are unlocked. It contains a VerticalLayoutGroup to automatically format achievements if there are multiple unlocked at once in a vertical layout.

When an achievement is unlocked, an AchievementNotification prefab is instantiated within the AchievementNotificationPanel with the name, description, and image passed to the AchievementNotification. This will adjust the notification's content according to the achievement. The AchievementNotification will then fade out and destroy itself.

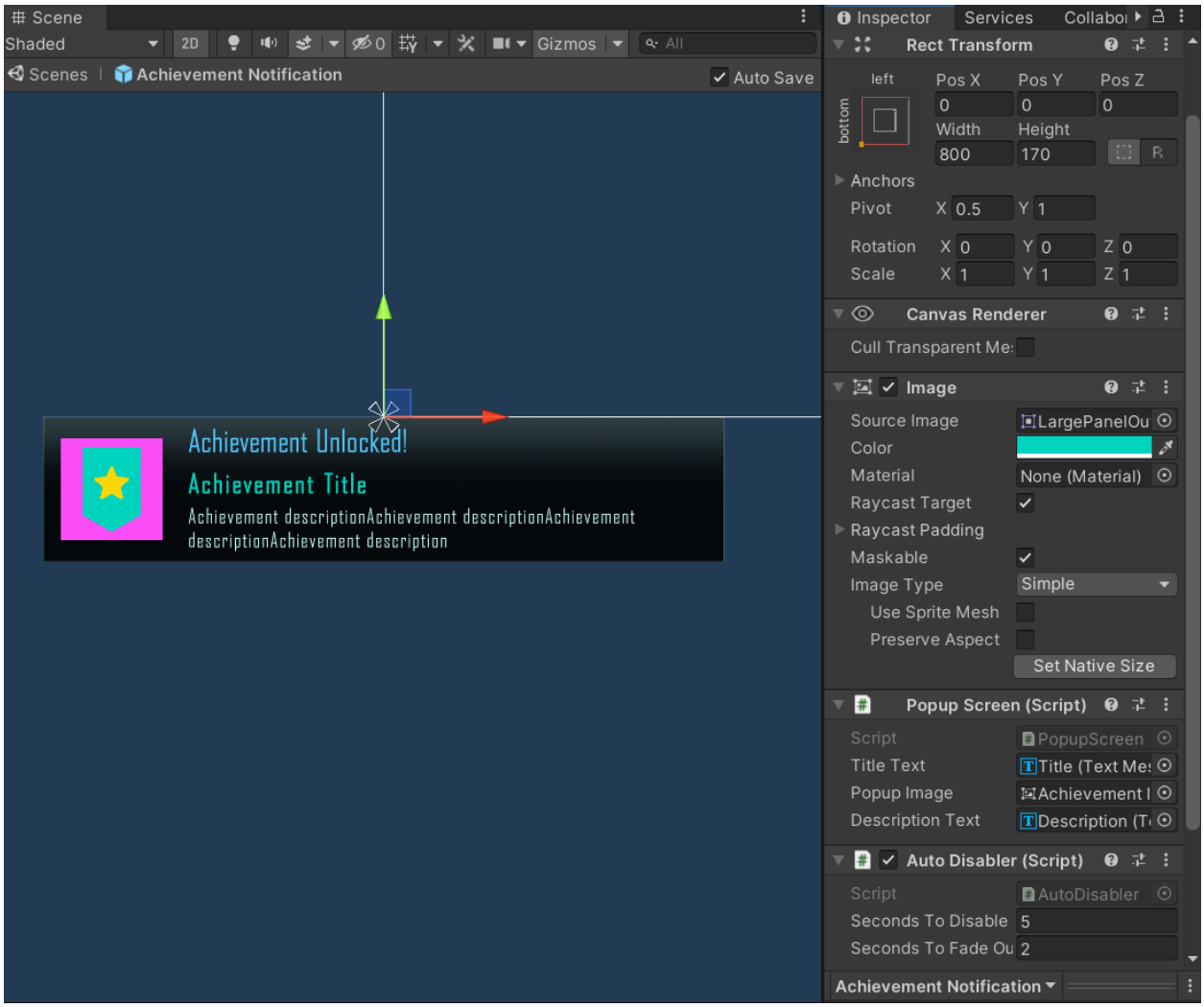


Fig. 40. The AchievementNotification image which will display the contents of an unlocked achievement.

7. Evaluation

In this section, the evaluation process of the product is described. There will be 3 evaluations conducted, a user testing conducted with volunteer participants, an evaluation of the MoSCoW requirements, and an evaluation with the client.

7.1. User Testing

The implementation of gamification in the product has the objective of providing feedback and engaging learners in the content, and satisfying their needs for competence and autonomy. The purpose of this user test is to evaluate the effectiveness of gamification at achieving these objectives.

7.1.1. Testing Setup

To test the effectiveness of gamification, two versions of the application will be used for testing. The first is the fully gamified application. The second is the same application but with as many gamified features stripped away to mimic the feedback that a fingerprint trainee would receive while in training. Testing will be conducted on 4 participants with a between-subjects design with these two versions of the application.

7.1.2. Non-gamified Changes

For the non-gamified version, the following changes were made to the application:

1. The progress bar is removed in the course menus
2. Exercises only have 1 difficulty that the participant must pass to proceed.
3. Rankings are removed.
4. Achievements are removed.
5. No feedback is provided between questions. Participants only see their total grades at the end of the exercise.
6. Statistics are not provided, and the profile section is removed.
7. Rewording of certain phrases to be less gamified and more academic and formal.
8. Removal of all interactive features in lessons.

7.1.3. Variables

Independent Variable
The independent variable of the user testing will be the version of the application the learner receives.

Dependent Variables
The dependent variables that will be measured during the test will be:

1. Time spent on exercises
2. Competency of participants
3. Autonomy of participants
4. Engagement of participants

These can be formulated into 4 different expectations during the experiments:

1. Participants will put in more time while working in the application when they interact with the gamified application which provides additional feedback to their actions compared to the non-gamified application.

   This will be measured by the total amount of time participants take to complete the compulsory tasks, or how much they have completed by the 1-hour mark.

2. Participants will perceive themselves to be more competent and perform better when receiving feedback in the gamified application than not receiving any in the non-gamified application.

   This will be measured through the 2nd questionnaire, as well as recording down the grades received for each exercise.

3. Participants will perceive themselves to have more freedom and autonomy in the gamified application compared to the non-gamified application.

   This will be measured through the questions provided in the 2nd questionnaire that focuses on the user's sense of autonomy.

4. Participants will be more engaged in the gamified application from receiving feedback and interacting with a more gameful experience and interface and be more motivated to perform further interactions within the environment than in the non-gamified application.

   This will be measured by the amount of time the participants choose to spend on the application, and if they choose to extend their session to interact with any features within the application.

7.1.4. Experiment Design

Before the experiment can begin, the formalities of the test have to be conducted. Participants will be provided with an information sheet and informed consent explaining the purposes of the test and what will happen during it. Participants will then have to sign the informed consent form to proceed. Participants will be randomly provided with one of two versions of the application and will be informed of which version they receive.

Throughout the experiment, participants will be provided with two questionnaires, one before the actual test and one after. The first questionnaire will be used to discover the existing knowledge

and intrinsic motivation the participant has towards the subject, as well as their experience with games or gamified applications. This will be used to control for any variables relating to the participants' past experiences that may alter the results of the test.

The testing duration will last for 1 hour by default. Participants will be provided with a list of compulsory tasks that they must complete within the hour. For the gamified version, these compulsory tasks are to finish every lesson and complete every beginner exercise, along with the intermediate minutiae exercise. For the non-gamified version, it is to simply finish every content.

Whether or not the compulsory tasks are completed when an hour has passed, the participant can choose to either end the session or extend to complete the tasks. Optional tasks will also be included for the gamified version that the participant can choose to complete during or after they have completed all of the compulsory tasks. These optional tasks are to complete harder exercise difficulties, get gold ranks for as many exercises as possible, and to get all the achievements. The session can also be extended if participants wish to complete these optional tasks after an hour has passed.

No recordings will be taken of the test. Instead, participants will be observed during the entire session, and notes will be taken on several points (see 6.1.6). Participants will be encouraged to think out loud and will be able to seek clarification from the researcher on the accuracy of provided answers as they may not be accurate which can be especially confusing.

The second questionnaire will then be provided which will question the participants on their perceived sense of competence and autonomy within the application. An interview may follow after to follow up on any interesting observations noted during the test, or on any answers answered in the questionnaires.

For participants with the non-gamified version, they will be briefly shown the gamified features and asked to complete a third questionnaire, which will question them on how they feel these gamified features would have affected their responses in the second questionnaire.

7.1.5. Questionnaires

Questionnaire 1

This first questionnaire is to determine the participant's background with regards to the implementation and the subject matter of the product.

1. What is your highest educational qualification that you have or are in the process of completing?
    a. Primary School
    b. Secondary School
    c. Polytechnic Diploma

d. Junior College
e. Bachelor's Degree
f. Masters Degree

This question is to simply determine the educational qualifications of participants.

2. Have you received any formal training or education in the fields of forensic science or fingerprint examination?

   This is a yes or no question and is to ensure that participants have no formal training or education in the subject matter.

3. How would you describe your existing knowledge in the fields of forensic science or fingerprint examination? Please seek clarification with the research if you are unsure of what to answer.

   a. No knowledge at all
   b. I have heard of it or seen it in pop culture
   c. I am aware of certain concepts within the field
   d. I have beginner knowledge in the field through research or training
   e. I am fairly knowledgeable in the field
   f. I am proficient in the field
   g. I am an expert in the field

   This question is to gain a deeper insight into the participant's knowledge of the subject matter.

The rest of the questions below are Likert scale statements from 1 to 7.

4. I am very comfortable and familiar with the usage of digital technology. Digital technology in this case refers to the usage of software in any form of device and operating system.

   This question is to control for and better understand any observed or complained frustrations with the use of the application that may have to do with the user's lack of experience with digital technology.

5. When I play a game, I am immediately aware of the purposes and mechanics of most game elements. Game elements refer to elements such as points, scores, achievements, statistics, progress bars, chapters, objectives, branching paths, currencies, etc…

   This question is to control for and better understand any participants' interactions with game elements and their reactions towards it.

6. My current intrinsic motivation to learn more about this topic is very high. Intrinsic motivation refers to your desire to do something without an external reward because it is fun and enjoyable.

   This question is to control for variations in participants' engagement towards the application and subject matter.

Questionnaire 2

This second questionnaire is to determine the effectiveness of feedback implemented within the application, as well as their sense of competence and autonomy within the application. All questions in this questionnaire are Likert scale statements from 1 to 7 unless stated otherwise.

1. I felt that the feedback I received in the application was useful and helped me identify and correct what I was doing wrong.

   This question is to determine the effectiveness of feedback implemented within the application.

2. I feel that the feedback I received was childish and not appropriate for the subject matter and content.

   This question is to determine how the participants feel about the feedback within the application and if they felt anything was inappropriate.

3. I feel like I have accomplished or learned something after interacting with the application.

   This question is to determine the participants' sense of competency based on how satisfied they feel with the work they have accomplished within the application.

4. I felt that I was provided with the right amount of challenge and was not overwhelmed by the content.

   This question is to determine the participants' sense of competency based on the level of challenge they encountered within the application and if they felt that they could handle the challenge or not.

5. I feel a sense of ownership over the work I have performed.

   This question is to determine the participants' sense of competency based on how proud and attached they feel to the work they have performed within the application.

6. I feel competent over the work I have done relative to what was expected of me.

This question is to determine the participants' perceived sense of competency based on the work they had performed within the application.

7. I feel that I had the freedom to challenge myself at my own pace.

   This question is to determine the participants' sense of autonomy based on whether they felt they had autonomy over the level of challenge they felt comfortable in partaking in within the application.

8. I felt that I had no freedom in my actions and I was being dictated over what to do within the application.

   This question is to determine the participants' sense of autonomy based on whether they felt pressured to perform specific tasks instead of feeling like their actions were their own within the application.

9. I felt frustrated over the interaction with the user interface which would have impacted my answers above.

   This question is to determine how the usability of the application may have caused frustration that may have impacted their sense of competence and autonomy.

10. Please describe, if any, your frustrations with the user interface.

    This question is open-ended and is a follow-up to the previous question to better understand any significant issues the participant had with the user interface.

11. I felt frustrated or confused over the clarity, delivery, or accuracy of the educational content I had to learn which would have impacted my answers above.

    This question is to determine how the content of the application may have affected their sense of competence and autonomy. For example, if the content was worded confusingly or their answers were graded against an incorrect answer sheet, this may leave them feeling less competent and autonomous than they would have been otherwise.

12. Please describe, if any, your confusions or frustrations with the clarity, delivery, or accuracy of the educational content.

    This question is open-ended and is a follow-up to the previous question to better understand any significant issues the participant had with the educational content.

Questionnaire 3

This questionnaire is only provided to participants who interacted with the non-gamified version of the application after being shown what the gamified features are that were not present in the

version of the application they were interacting with. All questions in this questionnaire are Likert scale statements from 1 to 7 unless stated otherwise.

1. I feel that the gamified features such as the statistics, achievements, and feedback received between each question would have helped me feel more accomplished and learned.

   This question is to determine how participants using the non-gamified version would feel if the implementation of the profile page, statistics, achievements, and general feedback in between questions would have positively impacted their experience within the application.

2. I feel that the gamified features such as the scoring system and feedback received between each question would have provided the feedback that would have helped me identify and correct what I was doing wrong.

   This question is to determine how participants using the non-gamified version would feel if the implementation of being able to view their scores and receiving general feedback in between questions would have helped them understand their mistakes and errors.

3. I feel that the gamified features would have been childish and not appropriate for the subject matter and content.

   This question is to determine how participants using the non-gamified version would feel about the appropriateness of the implementation of the various gamified features in the gamified version of the application.

4. Please describe, if any, the gamified features that you felt would have been childish and not appropriate for the subject matter and content.

   This question is open-ended and is a follow-up to the previous question to identify which features the participant feels would be inappropriate.

5. I feel that the gamified features such as separating difficulty would have helped me feel less overwhelmed by the content.

   This question is to determine how participants using the non-gamified version would feel if the implementation of different exercise difficulties would have helped them feel more competent about themselves.

6. I feel that the gamified features such as the profile section would have provided a sense of ownership over the work I had performed.

This question is to determine how participants using the non-gamified version would feel if the implementation of a profile section would have helped them feel more attached to their work done within the application.

7. I feel that the gamified features would have helped me feel more competent over the work I was doing relative to what was expected of me.

   This question is to determine how participants using the non-gamified version would feel if the implementation of the various gamified features would have helped them feel a greater sense of competence within the application.

8. I feel that the gamified features such as the separation of difficulty would have given me the freedom to challenge myself at my own pace.

   This question is to determine how participants using the non-gamified version would feel if the implementation of different exercise difficulties would have helped them feel a greater sense of autonomy with regards to being able to choose their challenges within the application.

9. I feel that the gamified features would have given me more freedom in my actions and be less dictating over what to do within the application.

   This question is to determine how participants using the non-gamified version would feel if the implementation of the various gamified features would have helped them feel a greater sense of autonomy within the application.

7.1.6. Observation Points

During the testing session, participants would be encouraged to think out loud what they feel about the various features, content, and challenges that they encounter within the application. In addition, observations will be made on several points about the participants' behaviour within the application.

In all sections of the application, observations would be made about the usability of the application. These include problems with navigating the application and confusion with any interaction with UI elements.

Within the main menu, observations would be made on any curiosity towards any feature, such as the profile section, statistics, achievements, different difficulties, and progress bar.

Within lessons, observations would be made on any reactions towards any interactive features within the lesson such as the hover and popup explanation features, and on any difficulties or reactions with the delivery of the educational content which may be confusing or difficult for them to understand.

Within exercises, observations would be made on any reactions towards feedback or the lack of feedback received, such as any signs of frustration and curiosity, comments made, or attention paid towards it. Observations would also be made on how competent participants are with the exercises and how quickly they can identify the various features that they have to annotate.

7.2. User Testing Results

7.2.1. Results

Effects of Results from Questionnaire 1

Questionnaire 1 is provided to participants before the user test begins to determine 4 things; their existing knowledge in the subject matter, their familiarity with digital technology, their familiarity with game mechanics, and their intrinsic motivation towards the subject matter.

It was determined that these variables did not affect the results from the test as most of their answers were very close to each other. There was an exception with one participant who responded with a significantly lower value for intrinsic motivation than the other participants, which may have affected the results in expectation 1 slightly.

Expectation 1: Longer Time Spent In Exercises

Based on the time recorded of how long it took every participant to complete the test, it was found that participants who interacted with the gamified version of the application spent a longer time completing the test than participants who interacted with the non-gamified version of the application. This also accounts for the extra time that participants interacting with the gamified version would have to spend with the beginner minutiae exercise.

At the 1 hour mark, every participant had reached the minutiae annotation exercise, with the exception of one of the non-gamified participants who had finished everything with about 8 minutes to spare. This participant notably answered with a significantly lower value of intrinsic motivation than every other participant, which may have affected the results. Participants interacting with the gamified version had only either just reached the minutiae annotation exercise or were only halfway through the first print at the 1-hour mark. This is strongly contrasted with participants from the non-gamified version who was well through the annotation exercise or had already completed it by the 1-hour mark.

These results are in line with the expectations.

Expectation 2: Higher Competency In Participants

Based on the observed results of every participant, there was no significant difference in the competency level of participants interacting with the gamified compared to the non-gamified versions. The only significant difference in results occurred with the core exercise.

By adding up the values of the responses to questions related to the user's sense of competency in questionnaire 2, it was found that participants interacting with the gamified version of the application experienced a slightly lower sense of competence compared to participants interacting with the non-gamified version of the application (40/56 vs 45/56).

The values of the responses to questions regarding frustrations with the user interface and educational content were also significantly higher in participants interacting with the non-gamified version of the application compared with participants interacting with the gamified version of the application. This means that the sense of competency in participants interacting with the non-gamified version should likely be higher. These results are therefore not in line with the expectations.

Expectation 3: Higher Autonomy In Participants

By adding up the values of the responses to questions related to the user's sense of autonomy in questionnaire 2, it was found that participants interacting with the gamified version of the application experienced a slightly higher sense of autonomy compared to participants interacting with the non-gamified version of the application (22/28 vs 19/28).

The values of the responses to questions regarding frustrations with the user interface and educational content were also significantly higher in participants interacting with the non-gamified version of the application compared with participants interacting with the gamified version of the application. This means that the sense of autonomy in participants interacting with the non-gamified version should likely be higher. These results are therefore not in line with the expectations as the difference in sense of autonomy may not be significant enough.

Expectation 4: Higher Engagement In Participants

None of the participants in both versions of the application chose to extend the session to further interact with the application. In addition, participants interacting with the gamified version of the application did not complete the compulsory tasks and chose to end the session after the 1-hour mark, compared to participants interacting with the non-gamified version of the application who completed the compulsory tasks either by the 1-hour mark or by extending the session by a significant amount of time. These results are therefore not in line with the expectations.

Usability and User Interface

There were several issues found with the usability of the application throughout texting. The most severe and universal one among all the participants was the font choice of the application, which participants found made it very tiring and difficult to read when there was a lot of text together. This may have made lessons seem more overwhelming than they were.

Another severe issue is that there were no obvious instructions on how to properly use the annotation tool, particularly with zooming in and out and with scrolling. This information was

hidden in the help button at the top right of the fingerprint image, which was again inside a pile of unnecessary information that participants did not bother to read through if they even realised that there was a help button.

Furthermore, many features that were supposed to help the participants were usually completely missed, especially with the hints provided in the beginner exercises and the lesson references available in the beginner and intermediate exercises. Notably, the feedback provided with the annotations on the fingerprint was very cluttered and not very obvious, and participants did not make use of it many times where it would have been beneficial to correct their mistakes. More could be done to highlight these features and make them more prominent to users.

Other smaller issues included an indicator for the course menu buttons to indicate if it is unlocked or completed or locked and having every button light up when you hover over them. Specific to the exercises, the annotation tool required a significant amount of polish and additional features to be comfortable to use. These would be highlighted in the Recommendations section later in the paper. Nonetheless, participants generally found that the user interface looked appealing, despite the usability issues.

Delivery of Lessons

Generally, participants felt that lessons required much more diagrams and images as certain slides lacked those and only contained text explanations. This is especially true for the core and delta lessons, where certain concepts were introduced without images. Furthermore, certain slides introduced too much information at once, which could be better broken down into separate slides. The wording used of certain terminologies, such as with friction ridges, had to be more consistent as well. Specifically, with friction ridges, it was sometimes used interchangeably with “lines”, which was confusing for some of the participants.

Effectiveness of Features

The gamified features were found to be very effective at conveying information and reducing frustration in participants. This is especially noticeable when looking at the last 2 Likert scale questions of questionnaire 2. Participants interacting with the gamified version of the application always responded with values less than 4 in terms of their frustration with the user interface and delivery of content compared to participants interacting with the non-gamified version of the application, who always responded with values above 4. This is quite a significant difference which indicates that the gamified features had a large impact on participants.

The feedback provided during exercises were not found to impact participants' sense of competency, however, and the inaccurate feedback provided may have played a role in this. Notably, participants who received feedback were observed to feel more frustrated when receiving incorrect feedback even after acknowledgement of the fact than participants who received no feedback at all. This likely significantly lowered their sense of competency.

However, when receiving accurate feedback, and where they used the feedback provided, it was effective at correcting their mistakes, and they did not repeat those mistakes in subsequent annotations.

The large amounts of frustration received from incorrect feedback may also indicate that the feedback provided on their performance may be very effective at conveying this information back at them and at engaging and motivating the user as users seemed to be greatly affected by it.

The features were also very positively received after being shown to participants who had interacted with the non-gamified version of the application. Participants generally reacted with excitement at the features as they were being shown to them, and exclaimed that these features would have been very useful and interesting to them. In the third questionnaire, participants all responded with a 6 or 7 as well, indicating very positive reactions towards the features. Participants who interacted with the gamified version of the application who already had these features from the start, however, generally did not react to the features at all.

7.2.2. Limitations

Experiment Design

One of the largest flaws of the experiment design was the short testing period of only 1 hour. This meant that learners felt that they had to rush through the application instead of taking their time exploring the application and its features. This was also not reflective of how an actual user may use the application, which would be in shorter usages over a longer period. Participants interacting with the gamified version of the application also mentioned that they would be interested to interact with the other features in the application not covered by the compulsory tasks, but as the test was performed fairly late in the night for these participants, they stated that as a factor for not choosing to extend the session. Due to the short testing period, statistics and achievements were also not very useful for the participants, which were more useful as long-term feedback.

Delivery of Content

The delivery of the content, especially with the accuracy and consistency, could be significantly improved. Particularly in lessons, the wordings used were not consistent at times and certain terminologies were not explained well. More diagrams and images could also be provided for certain explanations, which could also be broken down into smaller content as well. The accuracy of certain answers was also incorrect which were confusing and frustrating for those who encountered them, which caused them to perform worse.

Challenge of Content

The exercises that participants had to complete were typically much too easy to pass and complete, posing little challenge to them. Notably, the incremental increases in difficulty was too

small from beginner to expert, and usually not meaningful enough to provide any sort of variety or novelty. Typically, these changes only consisted of removing hints and references and very slightly lowered margins of error with annotations. Especially for participants interacting with the non-gamified version of the application who could only work on the hardest exercises and who received no feedback about how well they were performing until they completed the exercise, they were all surprised at how well they did when they received their grades. This indicated that they perceived the difficulty to be very high, but the grading was too lenient.

Challenges being too easy was also a design flaw identified in a previous study [22]. This same flaw was also present in this study and it is important that this mistake is not repeated in the future.

7.3. Evaluation on MoSCoW

Must Have:

1. The product must be able to impart fundamental knowledge on fingerprint examination that learners need to have to perform ACE-V.

   The product was very effective at imparting what I imagined would be fundamental knowledge, and participants were all fairly confident at annotating the various tested details by the end. In reality, however, there was much more to learn with regards to fundamental knowledge required to perform ACE-V and many more techniques involved than just annotating. However, it was also acknowledged by the client that it would have been unrealistic to address all of these in such a short timeframe.

2. The product must be able to track relevant statistics on learners' performances and behaviours and display this to the learner.

   Tracking of statistics was implemented and could be easily viewed in between the relevant exercises and in the profile page of the main menu. While it was not useful in the context of the user test, the product was able to track these statistics.

3. The product must have an annotation tool that allows:
   a. Annotation of specific details
   b. Zooming in and out of a fingerprint image

   The above tools were the bare minimum essentials to allow for annotations and were successfully implemented.

4. The product must be able to compare a learner's annotations against a provided answer to provide automatic grading.

The automated grading system was successfully implemented and fully working, and able to provide largely accurate feedback where the answers were accurate.

5. The product must utilise gamification to attempt to solve the 3 research questions.

   The 3 research questions are as follows:

   How effective is gamification in actively engaging learners in repetitive and monotonous tasks in perceptual learning?

   How effective will gamification be at developing a learner's sense of competence and autonomy?

   How effective is gamification at providing feedback to learners?

   Gamification was utilised to attempt to solve each of the 3. The effectiveness and success of it will be discussed in the Conclusion section (section 8).

6. The product must have a database of annotated prints to allow a minimal number of questions per exercise to be completed.

   A database was hand-selected from prints within the NIST Database acquired, and a sufficient number of prints were within the database to facilitate the implementation of exercises.

Should Have:

1. The product should train learners to become proficient with the usage of ACE-V and GYRO.
   The product did not manage to implement the above features.

2. The database of annotated prints should be sufficiently large to provide a mostly unique randomised set of prints per exercise attempt.

   The database built had a large enough number of prints to allow for a mostly random unique set of prints every exercise, and finding the same prints did occur occasionally but not often enough that it was distracting. This requirement was a partial success.

3. The answers that learners will be graded against should be as accurate as possible.

   The answers were provided by the researcher who was not an expert, and as such, were occasionally very inaccurate. However, it was accurate enough that the application largely still worked, and this requirement is, therefore, a partial success.

Could Have:

1. The product could provide a platform to freely work with random sets of fingerprints using ACE-V and GYRO.

   The product did not manage to implement the above features.

2. The annotation tool could provide additional quality of life improvements and features such as:
   a. Zooming in towards the mouse cursor
   b. Ridge tracing tool
   c. Free drawing

   None of the above features was implemented in the product.

7.4. Evaluation with Client

The client was very satisfied with the product and responded very positively to it when a live demonstration was done. The client was especially impressed with the level of content available despite very little input from her or any other experts. In particular, she noted that there is presently no such form of statistical capture on the performances of trainees and learners that this application can facilitate. She also adds that trainers can be very harsh and objective even though the work itself can tend to be very subjective. As such, this application can provide some form of objectivity and consistency to the training of such work.

A limitation pointed out is there is much more to the work than just being able to spot the details and annotate them. Especially with the annotation of minutiae, the technique of annotating them is also important and should be done systematically. Excluding a print also involves a more complex process where several other details of the print can be identified, allowing for a print to be excluded based on these details even before having to annotate the minutiae in a print.

In general, the client is very satisfied with the work put into the project and feels that there is certainly potential with furthering the development of this application.

8. Conclusion

The utilisation of digital technology to train fingerprint examiners has seen little adoption within the industry. In addition, it is plagued with issues cornering a lack of standardisation, statistical capture, and incremental training. This project attempts to mitigate some of these issues with the development of a gamified digital training platform to train the perceptual expertise of complete beginners with no knowledge of the field.

8.1. Research Questions

In this section, the research questions identified in the introduction will be answered. In the introduction, the main research question was identified as:

How effective will the implementation of gamification be in enhancing the training process of building perceptual expertise in fingerprint examiners?

Several sub-questions were then derived from that as:

1. *How effective will the implementation of gamification be in actively engaging learners?*
2. *How effective will the implementation of gamification be at satisfying a learner's need for competence and autonomy?*
3. *How effective will the implementation of gamification be at providing feedback to learners?*

1. *How effective will the implementation of gamification be in actively engaging learners?*

One of the main benefits of gamification is its ability to engage users in the application it is implemented in. This can be done through its various mechanics and gameful interfaces, which can make the experience more fun and enjoyable for users. Based solely on the evaluation conducted in this project, the implementation of gamification was not very effective at actively engaging learners. However, several limitations with the experiment design were acknowledged that may have impacted the results, and participants did mention that they would have liked to interact more with the application had they been given more space to play around with it. Participants also felt much less frustration with the application and felt more at ease while interacting with the gamified features, which were not considered as part of the evaluation criteria. As such, the implementation of gamification in this application was somewhat effective in actively engaging learners.

2. *How effective will the implementation of gamification be at satisfying a learner's need for competence and autonomy?*

To engage a user's intrinsic motivation, gamification has to be able to satisfy their need for competence and autonomy. This can primarily be achieved through providing positive feedback

to learners and emphasising choices and freedom within the application. The implementation of gamification within the application attempts to achieve this by providing encouraging feedback even if they performed poorly, rewarding them for a job well done, and providing a choice in challenges that users can choose to complete if they so wish. Through the evaluation conducted in the project, gamification was not able to satisfy the user's need for competence and actually resulted in a lower sense of competence compared to those who did not interact with any gamified elements. Gamification was, however, slightly better satisfying the user's need for autonomy, although this difference was not significant and it cannot be concluded that it was effective.

3. *How effective will the implementation of gamification be at providing corrective feedback to learners?*

Providing feedback is essential in correcting the mistakes a learner makes and crucial in any form of an educational programme. Without feedback, learners would never be aware of the mistakes they have made and would never correct themselves. Through gamification, immediate feedback is provided in between every question in the form of colours, scores, statistics, and visualisations. It was found that through such feedback, gamification was very effective at correcting the mistakes that learners make, and in some cases, these mistakes were not repeated after. However, issues with usability and inaccurate feedback marred the effectiveness at times and instead caused frustration.

9. Recommendations

The original vision of this project was very ambitious and as a result, many of the features could not be implemented. Below is a list of recommendations of what should be developed next and in the future, and what can be improved on.

Additional Content (In order of importance):

- Include ACE-V and GYRO capabilities and lessons.
- Include techniques in annotations and analysis of a print, such as how to annotate minutiae systemically, ridge counting, excluding a print based on other factors.
- Include more in-depth theoretical knowledge with closer collaboration with experts.
- Include a free work programme where learners can freely perform ACE on random prints and perform verification on the work of others.
- Implement networking to introduce a social aspect to the application. This allows the learners to verify and discuss each others' works. A forum can also be provided where learners can connect with each other and seek help from one another. Such a platform can also help to build a consensus towards specific standards.

Additional Features:

- Provide a way to view the annotations on a fingerprint of every user together.
- Add animations and sound effects.
- Save the learners' answers to every exercise so that they can review them.
- More statistical capture, for example, accuracy and precision per fingerprint pattern.

Annotation Improvements:

- Include information on clarity of prints, which can be used to provide more concise difficulty tiering of exercises.
- Have answer annotations be done by several experts. Grading can then be done based on the average of expert answers rather than only 1 which improves the reliability of grading. This is especially beneficial for grading minutiae.

Additional Annotation Tool Features and QOL Improvements:

- Allow the adjustment of contrast and gamma in the image.
- Allow the rotation and movement of fingerprint images.
- A fullscreen mode for annotating prints.
- Allow individual annotations to be scaled. This can help provide more accurate grading and matching of details as the size of the lifted fingerprint ridges can differ between regions.

- Include a free drawing tool, ridge tracing tool and grab tool. Include keyboard shortcuts for everything.

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Appendices

Appendix A: Results of Questionnaire 1

Participant 1

What is your highest educational qualification that you have or are in the process of completing?

Bachelors Degree

Have you received any formal training or education in the fields of forensic science or fingerprint examination?

- ○ Yes
- ◉ No

How would you describe your existing knowledge in the fields of forensic science or fingerprint examination? Please seek clarification with the research if you are unsure of what to answer.

- ○ No knowledge at all
- ◉ I have heard of it or seen it in pop culture
- ○ I am aware of certain concepts within the field
- ○ I have beginner knowledge in the field through research or training
- ○ I am fairly knowledgeble in the field
- ○ I am proficient in the field
- ○ I am an expert in the field

I am very comfortable and familiar with the usage of digital technology. Digital technology in this case refers to the usage of software in any form of device and operating system.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

When I play a game, I am immediately aware of the purposes and mechanics of most game elements. Game elements refers to elements such as points, scores, achievements, statistics, progress bars, chapters, objectives, branching paths, currencies, etc...

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

My current intrinsic motivation to learn more about this topic is very high. Intrinsic motivation refers to your desire to do something without an external reward because it is fun and enjoyable.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	◉	○	○	○	Strongly agree

Participant 2

What is your highest educational qualification that you have or are in the process of completing?

Bachelors Degree

Have you received any formal training or education in the fields of forensic science or fingerprint examination?

- ( ) Yes
- (•) No

How would you describe your existing knowledge in the fields of forensic science or fingerprint examination? Please seek clarification with the research if you are unsure of what to answer.

- ○ No knowledge at all
- ◉ I have heard of it or seen it in pop culture
- ○ I am aware of certain concepts within the field
- ○ I have beginner knowledge in the field through research or training
- ○ I am fairly knowledgeble in the field
- ○ I am proficient in the field
- ○ I am an expert in the field

I am very comfortable and familiar with the usage of digital technology. Digital technology in this case refers to the usage of software in any form of device and operating system.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

When I play a game, I am immediately aware of the purposes and mechanics of most game elements. Game elements refers to elements such as points, scores, achievements, statistics, progress bars, chapters, objectives, branching paths, currencies, etc...

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	◉	○	Strongly agree

My current intrinsic motivation to learn more about this topic is very high. Intrinsic motivation refers to your desire to do something without an external reward because it is fun and enjoyable.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	◉	○	○	○	Strongly agree

Participant 3

What is your highest educational qualification that you have or are in the process of completing?

Bachelors Degree

Have you received any formal training or education in the fields of forensic science or fingerprint examination?

- ○ Yes
- ◉ No

How would you describe your existing knowledge in the fields of forensic science or fingerprint examination? Please seek clarification with the research if you are unsure of what to answer.

- ○ No knowledge at all
- ◉ I have heard of it or seen it in pop culture
- ○ I am aware of certain concepts within the field
- ○ I have beginner knowledge in the field through research or training
- ○ I am fairly knowledgeble in the field
- ○ I am proficient in the field
- ○ I am an expert in the field

I am very comfortable and familiar with the usage of digital technology. Digital technology in this case refers to the usage of software in any form of device and operating system.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

When I play a game, I am immediately aware of the purposes and mechanics of most game elements. Game elements refers to elements such as points, scores, achievements, statistics, progress bars, chapters, objectives, branching paths, currencies, etc...

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

My current intrinsic motivation to learn more about this topic is very high. Intrinsic motivation refers to your desire to do something without an external reward because it is fun and enjoyable.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

Participant 4

What is your highest educational qualification that you have or are in the process of completing?

Bachelors Degree

Have you received any formal training or education in the fields of forensic science or fingerprint examination?

- ○ Yes
- ◉ No

How would you describe your existing knowledge in the fields of forensic science or fingerprint examination? Please seek clarification with the research if you are unsure of what to answer.

- ○ No knowledge at all
- ◉ I have heard of it or seen it in pop culture
- ○ I am aware of certain concepts within the field
- ○ I have beginner knowledge in the field through research or training
- ○ I am fairly knowledgeble in the field
- ○ I am proficient in the field
- ○ I am an expert in the field

I am very comfortable and familiar with the usage of digital technology. Digital technology in this case refers to the usage of software in any form of device and operating system.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

When I play a game, I am immediately aware of the purposes and mechanics of most game elements. Game elements refers to elements such as points, scores, achievements, statistics, progress bars, chapters, objectives, branching paths, currencies, etc...

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

My current intrinsic motivation to learn more about this topic is very high. Intrinsic motivation refers to your desire to do something without an external reward because it is fun and enjoyable.

	1	2	3	4	5	6	7	
Strongly disagree	○	◉	○	○	○	○	○	Strongly agree

Appendix B: Results of Questionnaire 2

Participant 1 (Non-Gamified)

I felt that the feedback I received in the application was useful and helped me identify and correct what I was doing wrong.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	◉	○	○	○	Strongly agree

I feel that the feedback I received was childish and not appropriate for the subject matter and content.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	◉	○	○	○	Strongly agree

I feel like I have accomplished or learned something after interacting with the application.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

I felt that I was provided with the right amount of challenge and was not overwhelmed by the content.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	◉	○	Strongly agree

I feel a sense of ownership over the work I have performed.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

I feel competent over the work I have done relative to what was expected of me.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

I feel that I had the freedom to challenge myself at my own pace.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

I felt that I had no freedom in my actions and I was being dictated over what to do within the application.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	◉	○	○	○	○	Strongly agree

I felt frustrated over the interaction with the user interface which would have impacted my answers above.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

Please describe, if any, your frustations with the user interface.

Unable to grab finger print images for ease of observing various parts of it

I felt frustrated or confused over the clarity, delivery, or accuracy of the educational content I had to learn which would have impacted my answers above.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

Please describe, if any, your confusions or frustations with the clarity, delivery, or accuracy of the educational content.

Lack of visual aid when explaining key points, terminologies are not consistent and rather confusing at times, unable to review my answers and cross reference to the correct answers.

Participant 2 (Gamified)

I felt that the feedback I received in the application was useful and helped me identify and correct what I was doing wrong.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

I feel that the feedback I received was childish and not appropriate for the subject matter and content.

	1	2	3	4	5	6	7	
Strongly disagree	○	◉	○	○	○	○	○	Strongly agree

I feel like I have accomplished or learned something after interacting with the application.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	◉	○	Strongly agree

I felt that I was provided with the right amount of challenge and was not overwhelmed by the content.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	◉	○	Strongly agree

I feel a sense of ownership over the work I have performed.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	◉	○	○	○	Strongly agree

I feel competent over the work I have done relative to what was expected of me.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

I feel that I had the freedom to challenge myself at my own pace.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

I felt that I had no freedom in my actions and I was being dictated over what to do within the application.

	1	2	3	4	5	6	7	
Strongly disagree	○	◉	○	○	○	○	○	Strongly agree

I felt frustrated over the interaction with the user interface which would have impacted my answers above.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	◉	○	○	○	○	Strongly agree

Please describe, if any, your frustations with the user interface.

TEXT CHOICE COULD BE BETTER FOR BETTER READABILITY. the scrolling for the pics when doing the dotting exercises can be refined.

I felt frustrated or confused over the clarity, delivery, or accuracy of the educational content I had to learn which would have impacted my answers above.

	1	2	3	4	5	6	7	
Strongly disagree	○	◉	○	○	○	○	○	Strongly agree

Please describe, if any, your confusions or frustations with the clarity, delivery, or accuracy of the educational content.

Participant 3 (Gamified)

I felt that the feedback I received in the application was useful and helped me identify and correct what I was doing wrong.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

I feel that the feedback I received was childish and not appropriate for the subject matter and content.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	◉	○	○	○	Strongly agree

I feel like I have accomplished or learned something after interacting with the application.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	◉	○	Strongly agree

I felt that I was provided with the right amount of challenge and was not overwhelmed by the content.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

I feel a sense of ownership over the work I have performed.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

I feel competent over the work I have done relative to what was expected of me.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	◉	○	Strongly agree

I feel that I had the freedom to challenge myself at my own pace.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	◉	○	○	○	Strongly agree

I felt that I had no freedom in my actions and I was being dictated over what to do within the application.

	1	2	3	4	5	6	7	
Strongly disagree	◉	○	○	○	○	○	○	Strongly agree

I felt frustrated over the interaction with the user interface which would have impacted my answers above.

	1	2	3	4	5	6	7	
Strongly disagree	○	◉	○	○	○	○	○	Strongly agree

Please describe, if any, your frustations with the user interface.

Font, font size

I felt frustrated or confused over the clarity, delivery, or accuracy of the educational content I had to learn which would have impacted my answers above.

	1	2	3	4	5	6	7	
Strongly disagree	◉	○	○	○	○	○	○	Strongly agree

Please describe, if any, your confusions or frustations with the clarity, delivery, or accuracy of the educational content.

NA

Participant 4 (Non-Gamified)

I felt that the feedback I received in the application was useful and helped me identify and correct what I was doing wrong.

	1	2	3	4	5	6	7	
Strongly disagree	○	◉	○	○	○	○	○	Strongly agree

I feel that the feedback I received was childish and not appropriate for the subject matter and content.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	◉	○	○	○	Strongly agree

I feel like I have accomplished or learned something after interacting with the application.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	◉	○	Strongly agree

I felt that I was provided with the right amount of challenge and was not overwhelmed by the content.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

I feel a sense of ownership over the work I have performed.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	◉	○	○	○	Strongly agree

I feel competent over the work I have done relative to what was expected of me.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	◉	○	○	○	Strongly agree

I feel that I had the freedom to challenge myself at my own pace.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	◉	○	○	Strongly agree

I felt that I had no freedom in my actions and I was being dictated over what to do within the application.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	◉	○	○	○	Strongly agree

I felt frustrated over the interaction with the user interface which would have impacted my answers above.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	◉	○	Strongly agree

Please describe, if any, your frustations with the user interface.

THE TEXT! need music and also more visual examples...i'm more of a visual person so i rather see images than text

I felt frustrated or confused over the clarity, delivery, or accuracy of the educational content I had to learn which would have impacted my answers above.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	◉	○	Strongly agree

Please describe, if any, your confusions or frustations with the clarity, delivery, or accuracy of the educational content.

would be good to know what was right or wrong on the get go. UI can be better? :)

Appendix C: Results of Questionnaire 3

Participant 1

I feel that the gamified features such as the statistics, achievements, and feedback received between each question would have helped me feel more accomplished and learned.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

I feel that the gamified features such as the scoring system and feedback received between each question would have provided the feedback that would have helped me identify and correct what I was doing wrong.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

I feel that the gamified features would have been childish and not appropriate for the subject matter and content.

	1	2	3	4	5	6	7	
Strongly disagree	◉	○	○	○	○	○	○	Strongly agree

Please describe, if any, the gamified features that you felt would have been childish and not appropriate for the subject matter and content.

None

I feel that the gamified features such as seperating difficulty would have helped me feel less overwhelmed by the content.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

I feel that the gamified features such as the profile section would have provided a sense of ownership over the work I had performed.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

I feel that the gamified features would have helped me feel more competent over the work I was doing relative to what was expected of me.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

I feel that the gamified features such as the seperation of difficulty would have given me the freedom to challenge myself at my own pace.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

I feel that the gamified features would have given me more freedom in my actions and be less dictating over what to do within the application.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

Participant 4

I feel that the gamified features such as the statistics, achievements, and feedback received between each question would have helped me feel more accomplished and learned.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

I feel that the gamified features such as the scoring system and feedback received between each question would have provided the feedback that would have helped me identify and correct what I was doing wrong.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

I feel that the gamified features would have been childish and not appropriate for the subject matter and content.

	1	2	3	4	5	6	7	
Strongly disagree	○	◉	○	○	○	○	○	Strongly agree

Please describe, if any, the gamified features that you felt would have been childish and not appropriate for the subject matter and content.

I feel that the gamified features such as seperating difficulty would have helped me feel less overwhelmed by the content.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	◉	○	Strongly agree

I feel that the gamified features such as the profile section would have provided a sense of ownership over the work I had performed.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	◉	○	Strongly agree

I feel that the gamified features would have helped me feel more competent over the work I was doing relative to what was expected of me.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

I feel that the gamified features such as the seperation of difficulty would have given me the freedom to challenge myself at my own pace.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	◉	Strongly agree

I feel that the gamified features would have given me more freedom in my actions and be less dictating over what to do within the application.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	◉	○	Strongly agree

Appendix D: References and Assets Used in Perceptual Trainer

User Interface and Icons

120 UI Pack icon: https://dribbble.com/shots/6592214-120-UI-Pack-icon-free-download

Icons set: https://assetstore.unity.com/packages/p/icons-set-58217

Beautiful Progress Bar Free: https://assetstore.unity.com/packages/2d/gui/icons/beautiful-progress-bar-free-194904

Slim UI - Tech Menu: https://assetstore.unity.com/packages/p/slimui-tech-menu-133049

Images

K. N. Win, K. Li, J. Chen, P. F. Viger, and K. Li, "Fingerprint classification and identification algorithms for criminal investigation: A survey," *Future Generation Computer Systems*, vol. 110, pp. 758–771, 2020.

https://www.youtube.com/watch?v=cCoeK_pYJu0&list=PL3aHcYQc3ioQWu-GyFJLol3bMnDjdzywX&index=2

https://www.pcworld.com/article/2456640/stealthy-web-tracking-tools-pose-increasing-privacy-risks-to-users.html

Fingerprint core image examples provided by Caroline Gibb and scanned from "Classification and Uses of Fingerprints. The Australian modification and extension. Edward Richard Henry. 1941"

Fonts

Agency FB pre-installed from Microsoft (only in screenshots and not in any distributed build)

Roboto Mono: https://fonts.google.com/specimen/Roboto+Mono?query=Christian+Robertson#standard-styles

Fingerprint Database

NIST Special Database 300: https://nigos.nist.gov/datasets/sd300/request