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Training air Traffic Controllers Through Digital Mobile Applications Versus Traditional Methods

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Abstract: Safety-critical industries, such as air traffic control, are highly regulated, with rigorous processes and procedures to ensure that safety remains of paramount importance despite the business environment. Training personnel in safety-critical industries is therefore typically a lengthy and expensive process. Gamification and the emphasis on fun, entertainment, progression and retention of concepts has been shown to deliver strong engagement amongst learners but remains at odds with training for safety-critical industries. This paper explores the impact of gamified digital applications versus more traditional training methods for the training of air traffic controllers (ATCs) and other roles relating to air traffic services. We explore the impact of the user experience on engagement and learning retention through the testing of two digital mobile applications, Location Indicators (LI) and The Aircraft Control Positions Operator (ACPO) Starter Pack. These prototypes examine how air traffic control training could be improved by digital applications. In an industry where the rate at which trainees can be trained is projected to fall short of the demand for staff to work in the air traffic industry (BBC, 2018) this project examines potential opportunities for changing established training methods. Each application presented key learning areas for trainees in the air traffic control industry and offers an alternative to the equivalent training currently used. The prototypes were designed to provide a succinct user experience that sat alongside gamified elements to improve engagement. These were then evaluated to determine whether they were effective in potential trainee learning.

Keywords: User Experience, Games-Based Learning, digital training, m-learning, e-learning

1. Introduction

Training to be an operational ATC is an intense process, taking several years to complete (Humphreys, 2017). Pre-screening tests mean only 1% of applicants progress to the training phase (BBC, 2018). ATCs can retire at the age of fifty-five in the UK (The Pensions Advisory Service, n.d.) whilst in the United States ATCs must retire at fifty-six (Federal Aviation Administration, 2017). Early retirement for ATCs is more feasible due to relatively high incomes (especially those in senior positions) (National Careers Service, n.d.). ATCs with significant experience often find themselves in roles as teachers to trainees (National Research Council, 1997). Whilst in teaching roles, these ATCs are not in operations. With the number of flights, pre COVID-19 expected to increase by 500,000 per year until 2030 (BBC, 2018), there was an urgent need to recruit and train ATCs.

Air traffic services companies have sought to address these issues by attempting to recruit more applicants to apply to be ATCs (BBC, 2018). The Federal Aviation Administration (FAA) is expecting to recruit thousands of ATCs (Lane, 2018) and one company developed mini-games which direct users to their careers page (NATS, n.d.). To train ATCs requires time, and significant investment, with a single trainee costing around £600,000 (Savill, 2009). The current training process is "no longer engaging the current generation of trainees" and if changes are not made, there will be a decrease in trainees becoming operational ATCs (Humphreys, 2017). Millennials, individuals born between 1979 and 1994 (Myers & Sadaghiani, 2010), will make up ~35% of the workforce (ManpowerGroup, 2016) and reportedly react positively to e-learning tools (Oblinger, 2003).

This paper presents the output of a joint academic-industry collaboration between academics and a leading air traffic services company. The project explored how gamification, technology and user experience could improve the existing ATC training. This paper will reference the usability testing but focus on the learning effectiveness, drawing conclusions on the potential effectiveness for teaching and engaging users.

2. Literature Review

2.1 User Experience (UX)

User Experience (UX) relates to HCI and Ergonomics with the term 'user experience' originating from HCI and UCD (Law, et al., 2009). Focusing on the principles of UCD, Norman (1988) defines UCD as "a philosophy based

on the needs and interest of the user, with an emphasis on making products usable and understandable". In digital applications, the UX is considered an important measure for products to meet user needs, improve engagement and subsequently increase the time a user spends interacting with the product (Hart, et al., 2012). The goal is to benefit the user who is interacting with the product, making elements of the experience more enjoyable and easier to use. Training programs with crafted user experiences can engage users in order to increase the effectiveness of the applications learning content. With complex information required learning for ATC trainees, and the younger age of trainees, the application of UX design principles to digital learning tools could create more effective training programs. This also considers technology interaction as involving people "emotionally, intellectually and sensually" and emphasising that "we don't just use technology, we live it". (McCarthy & Wright, 2004). UX designers need to be able to empathise with their user's emotions and the project applied an integrated UCD approach that considered the users' needs as paramount.

2.2 ATC Training

ATCs gain an operational licence after ~18 months college based practical and theory-based training, followed by operational training (NATS, n.d.). The work involves processing real-time complex data in an environment where decisions have to be made quickly and safely (Cordeil, et al., 2016; Perry, et al., 2017). However, the air traffic services industry has historically underutilized the use of new technology. The process of integrating new technology so that it can become usable within operations is often lengthy. This process includes the development of the technology, new operational procedures, the necessary testing, developing the terminology and training people to use it, usually within a large organisation. Slower adoption of technology usage is inherent to the nature of the air traffic services industry. Any safety critical industry needs to ensure that any new technology or procedure meets existing safety and efficiency standards before they can become operational (Haissig, 2013). ATC training currently consists of computer simulators alongside other practical and theory-based training existing in both operations and classroom environments. Solutions using cutting-edge technology have experimented with making data-handling easier for ATCs and explored the use of Augmented Reality (AR) technology to make the traditional stripboard approach of flight tracking more efficient. A Virtual Reality (VR) application to facilitate remote working between ATC experts within a collaborative play space was also worked on (Cordeil, et al., 2016). Perry created 'Swivl' a digital tool which gives users the ability to revisit simulations and videos from classroom activities, surmising that digital learning tools can increase the rate at which students learn (Perry, et al., 2017). Despite the positive impact digital learning can have on students to increase engagement (Sousa, et al., 2017), ATC training digital learning tools are underused as self-learning interventions. This has a negative impact on validation, recruitment and training but also potentially for safety (The Economist, 2016).

2.3 Gamification

Gamification is the use of game-based mechanics and features to increase both motivation and engagement for non-gaming experiences (Seixas, et al., 2016; Thom-Santelli, et al., 2012). Increasing enjoyment and motivation through gamification in applications that teach or train, can increase a student's learning rate and retention (Darejeh & Salim, 2016). In the past, gamified training has been used to engage trainees and encourage them to learn through formats such as point-based systems, leaderboards, achievements and reward systems. These mechanics help motivate users to interact for longer periods. Quizzes are used as an evaluation method to provide positive feedback to users and for trainers to gain an insight into the progress of their students. Feedback gathered from quizzes can allow for users to see the areas which need further study. Gamification can also improve self-learning tools and gamified workplaces viewed as "self-improving, self-learning entities" (Oprescu, et al., 2014).

3. Methodology

3.1 Development Process

The project undertook a mixed-methods approach (Creswell & Clark, 2007). To understand the challenges of our target user group we observed ATC's and other individuals in relevant roles in air traffic services. Initial designs then focused on addressing issues uncovered. Workshops were held to gain further understanding of user needs and trainees' opinions of current training. Trainees often found training a very demanding process and thought current self-learning interventions could be improved. Game jams explored gamification and different technologies (PC, VR, AR) were evaluated before mobile technology emerged as preferable. Mobile technology provided a flexible and almost universally used tool (Deloitte, 2017). Throughout the design process, the prototypes were designed in-line with the principles of UCD (Abras, et al., 2004). The apps developed iteratively

through an Agile methodology (Fowler & Highsmith, 2001) allowing adaptation according to trainee ATC feedback (Abras, et al. 2004). The created prototypes (LI and ACPO Starter Pack) have both undergone user testing as the focus of this study.

Throughout the development process, the design philosophy of Dieter Rams and their ten principles for good design (de Jong, et al., 2017) influenced decisions. The principles of 'good design makes a product useful', and 'honest design' (de Jong, et al., 2017) were applied to convey information simply and intuitively. The ACPO Starter Pack added animations and images to enhance value. LI applied the principle, "good design is as little design as possible" (Lovell, 2011) reducing interaction to swipes and matching that simplicity in the visuals, with colour used sparingly. The applications applied differing design approaches to determine which, if any, were successful.

3.2 Design of Location Indicators Mobile Application

LI was designed to test knowledge of International Civil Aviation Organization (ICAO) codes which are four-letter codes assigned to every airport and aviation facility globally. ATCs and pilots use them to reference different locations via radio. For example, Edinburgh Airport is EGPH: 'E' is the continent (Europe), the 'G' is the country (United Kingdom), the 'P' represents a region within the country (Scotland) and the 'H' is the unique identifier of the airport (World Airport Codes, n.d.). Learning codes is difficult, trainees often study in groups and use flashcards. Observation revealed problems, being self-made, flashcards can have spelling errors and trainees frequently associate airports with the incorrect ICAO code. Flashcards are awkward to carry, especially with the number of ICAO codes a trainee is required to learn. LI was designed to provide a flexible and accurate learning tool that could deliver sector specific ICAO codes.

The app aims to be an effective self-learning tool for both ATC trainees and operational ATCs. LI mimics the existing process of learning ICAO codes through flashcards. Designed to be as simple as possible, the user only swipes left or right to interact with LI (Wobbrock, et al., 2009). LI takes advantage of gamification via a scoring system which provides user feedback. This score informs the player what codes they got right or wrong and was designed to motivate the user to improve by presenting them with clear understanding of where they should focus their learning. The application is flexible, allowing the user to different 'regions' for varying amounts of time, and portable by being playable on mobile devices, eliminating the need for physical flashcards. LI is designed as both a learning and retention tool, teaching ICAO codes to trainees and for providing experienced ATCs refresher training. LI is updateable, with an accessible database that hold codes and serves to manage the different regions within the application. Regions are a collection of ICAO codes, grouping codes into regions enables users to learn or retain the knowledge for a specific airspace sector.

3.3 Design of ACPO Starter Pack

The design of the ACPO Starter Pack required a different approach. ACPOs are 'pseudo-pilots' who operate within a simulator posing as pilots, this enables trainee ATCs to communicate with a pilot in the same way they would be expected to when in operation. For trainee ATCs, communicating with pilots is a key part of the role. ACPOs are expected to act the same way as pilots and possess the same knowledge. To learn this, ACPOs are given documentation detailing what is required learning for the role. The documentation is often challenging for individuals to grasp due to the variety and complexity of information contained. The pack is heavily text based with few visuals and trainees find it to be unengaging. As part of this study, a digital version of the ACPO Starter Pack was created for mobile devices. The application contains the same information as the original but utilises animation and images to explain complex concepts to the user and present a succinct user experience. The inclusion of moving images breaks up text and delivers learning content in an engaging bitesize format. Users interact with arrow buttons to navigate between pages or use the contents page to go to a specific topic. The ACPO Starter Pack, was developed using the design tool Principle. Principle enabled the creation of interactive designs and allowed for rapid iteration based on feedback using instant deployment on iOS devices.

3.4 Design of Retention Testing

To measure the learning effectiveness of both applications we designed testing for two participant groups undertaking a longitudinal study in which one group used the developed applications to learn specific educational content, and the other group using existing training materials. Over a working week, participants utilised their given learning material before completing an assessment at the end of the week. With both groups learning via different learning tools, we can compare the learning quality of the existing training material and the m-Learning equivalent by assessing participants' learning retention. Throughout the process we

endeavoured to replicate the same learning process trainee ATCs and ACPOs go through concerning the self-learning process. To achieve this, we encouraged participants using the existing training to come up with learning methods they felt best suited their preferred learning style. In the middle of each testing week, participants from each group assembled to undertake a group session where they would quiz each other using their respective learning tool.

Quantitative data was collected via assessments whilst a feedback form was used to collect qualitative data relating to the study, learning materials, learning methods and demographic data. Qualitative data gives us an understanding of what learning methods individuals utilised and their reaction to their given learning material. The feedback collected provided insight into current training methods as well as the design of the applications, building upon feedback collected as part of usability testing. Analytics were used throughout the testing process for the LI application. Play time, correct or incorrect answers, accuracy, date and time of each individual play session for each participant was recorded. The data provided insights into individual performance, the rate at which they learn and their learning habits.

Participants were informed of the protocols and schedule before a being given a brief introduction to the training material (both mobile and paper-based). Participants were encouraged to use different learning methods and were told to spend a minimum of fifteen minutes every day on each subject area, whether that be the contents of the ACPO Starter Pack or ICAO codes through their respective learning tool. Group learning sessions were conducted midway before assessments and feedback forms were completed at the end of the week. Assessments involved participants answering questions based on the information within the ACPO Starter Pack or corresponding ICAO codes. Participants self-reported time spent each day to record averages which were cross checked with the analytics data.

4. Results

4.1 Assessment Results

The study produced quantified assessment scores for both the traditional learning group (TL) (n = 16) and the digital learning group (DL) (n = 16). To create these quantified assessment scores, we averaged the assessment score for both groups. For the TL group, they scored an average of 24 from 64 answers for the LI assessment whilst scoring a total of 17 out of 37 on the ACPO Starter Pack assessment. For the DL group, they achieved a score of 25 from 64 for the LI assessment and scored 16 out of 37 for the ACPO Starter Pack assessment.

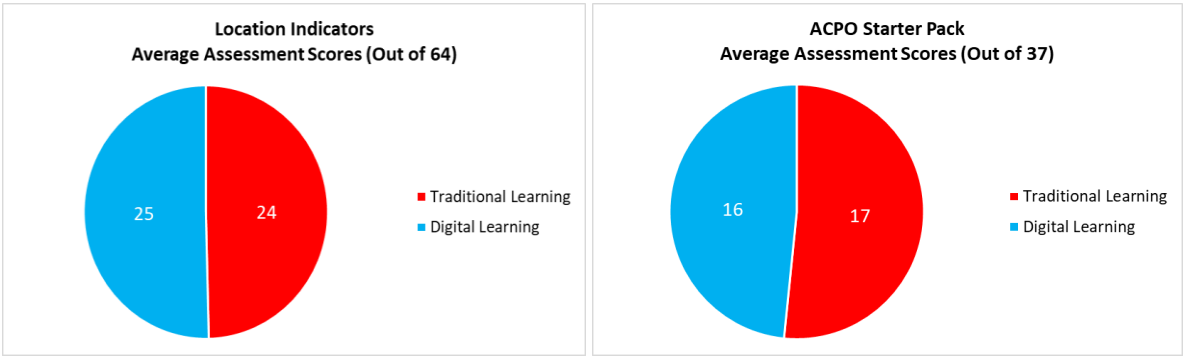

Figure 1: Average Assessment Scores for both the Traditional Learning and Digital Learning Groups for the ACPO Starter Pack and LI

4.2 Results from LI analytics

Utilising bespoke analytics embedded within LI, additional data was collected concerning player's behaviour in the retention testing of the LI app.

4.2.1 Participant accuracy over time

Analysing participants play sessions over the cumulative time they spent with the LI app (See Figure 2), participants consistently improved their accuracy scores. Accuracy further improves over time when analysing the accuracy of each play session of a participant (See Figure 3). The latter is regardless of date and time, only referencing the accuracy of each play session in sequential order for each individual participant. This trend of improvement is generally consistent when accuracy is collected via both methods. There are exceptions with

some participants accuracy fluctuating when analytics are collected by using accumulative time data instead of by individual play session.

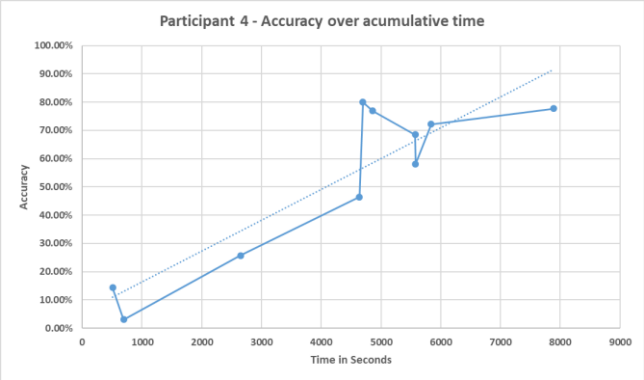

Figure 2: Accuracy over accumulative time (secs) for Participant 4 using LI

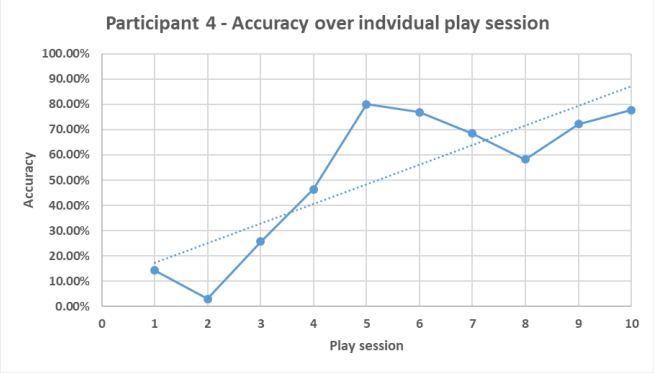

Figure 3: Accuracy over accumulative sessions for Participant 4 using LI

4.2.2 Playtime over dates

The amount of time spent with the LI application was also recorded over the duration of the playtest through the analytics (See Figure 4). The results show that some participants were consistently engaged with the training.

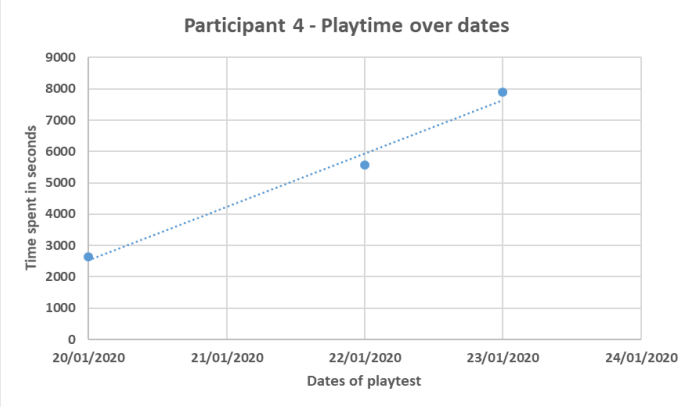

Figure 4: Playtime over dates for participant 4 using LI

4.2.3 Accuracy range per participant

The range of individuals accuracy over their usage of the LI application was tracked to gain an understanding of the participants overall performance. There is a high degree of variability in the accuracy within participants play tests and across participants (Figure. 5). Some participants performed relatively poorly from the start and did not improve, whilst some improved considerably, and others performed consistently well through the study.

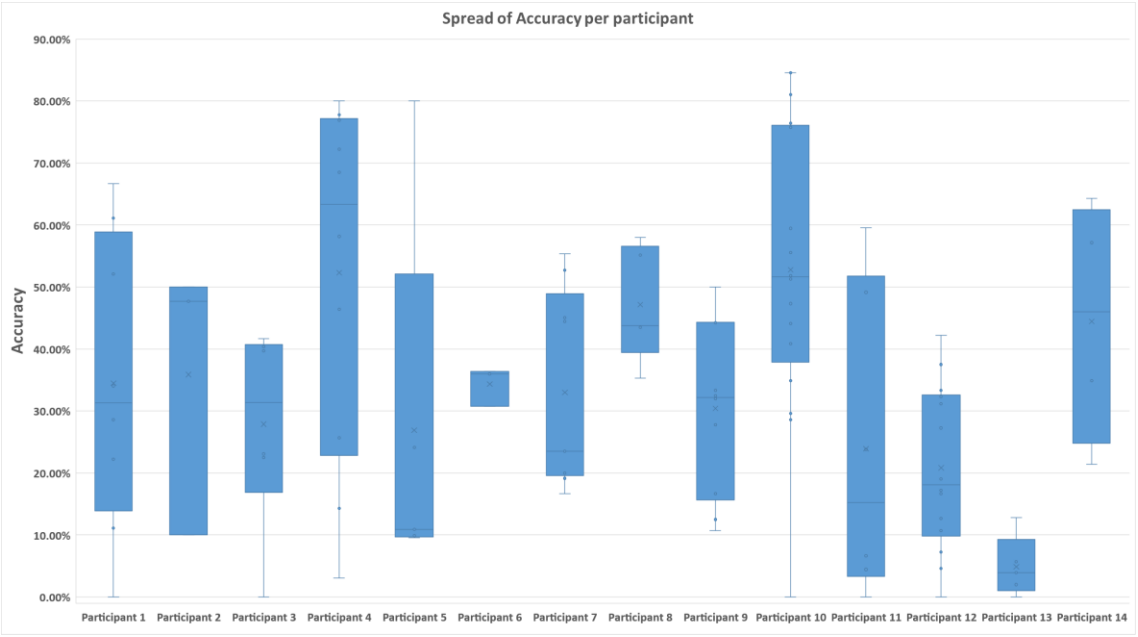

Figure 5: Accuracy range for each participant using LI

4.3 Results from time sheet

Participants from both groups self-reported the time they spent with the ACPO Starter Pack and LI, across the DL and TL materials. The self-reported times results with varied assessment scores achieved and with no identifying trends.

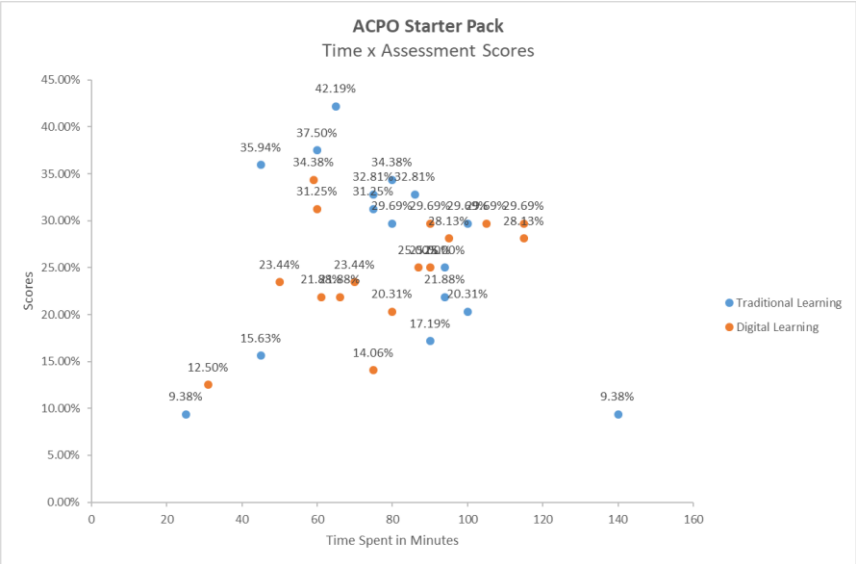

Figure 6: Time in relation to assessment score per participant for the ACPO Starter Pack

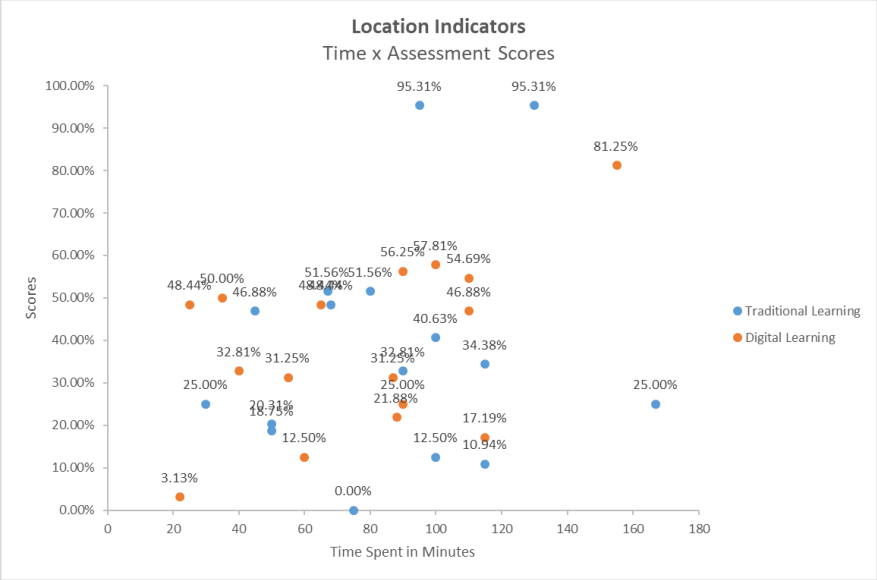

Figure 7: Time in relation to assessment score per participant for LI

4.4 Feedback forms

Feedback forms distributed to participants at the end of the study sought to ascertain opinions on the learning material, the study and how participants utilised the learning material assigned. Demographic information was also collected from participants concerning age, university course enrolled in, gender and English as a first language. Of the 32 participants (14-f, 18-m), mean age was 22 (range 18-28), all but two were students and 12 were undergraduates enrolled in a Game Design course.

4.4.1 English as first language

The differences in assessment scores between the English as a first language group and non-native English speakers was negligible. 13 participants identified English as their first language. The non-native English speakers group achieved assessment scores of 17 and 26 for LI and ACPO Starter Pack respectively, compared to scores of 16 and 22 for English as first language group.

4.4.2 Methods and techniques used to assist learning

Participants used a variety of different methods to learn. These ranged from word association, creation of stories to better remember information, note taking, flashcards, self-examination, map creation to assign a real-life location to ICAO codes, repeated readings, highlighting key information and using physical reminders.

4.4.3 Reflections on the on the study

Participants consistently stated that they would prefer to undertake the study for a longer period. Many participants felt the study ran well but that they had lot of information to learn over the period. Participants suggested the study should have been undertaken with non-native and native English speakers separated. This was recommended by non-native English speakers who felt they were at a disadvantage due to their lack of English language familiarity.

4.4.4 Suggestions on how learning could be improved

Participants suggested more use of colour coding for both the ACPO Starter Pack application and for the LI traditional learning materials would help the User Experience.

Participants commenting on the ACPO Starter Pack content and how it presents information suggested that the mobile application needed more interactive elements including the addition of a quiz element for self-evaluation and preferred more directly gamified elements, such as “connecting the call signs to the correct airline or putting the right names in the correct airspaces”. Participants identified issues with the speed that animations played and being unable to pause animations that taught the phonetic alphabet. Although favourable to animations, some noted that it made text more difficult to read when they were playing. Participants identified grammatical issues that made “sentences difficult to read and understand the first time.” The digital app was favoured over

paper version, which was viewed by participants as "disorganized" with much of the content being unstructured. One participant stated: "It feels like a collection of random facts with little point of reference to memorise" and participants wanted content to be reframed in a different manner.

For LI, participants' comments related to the user experience. The LI app needed better initial explanation and improved clarification as swiping "implies a true/false format" rather than right/wrong. Participants felt that the context needed better introduction. To improve the learning experience, participants suggested dividing the learning content, suggesting to "add in more [code] when the user starts to consistently get the codes right." One common recommendation from participants was to include a map in LI. Participants said by utilising a map, they could assign a code to a geographical location to make memorising the locations and their respective ICAO codes easier.

5. Discussion

This study measures the effectiveness of two mobile applications at teaching material on a self-study basis. Comparing final assessments across the two groups shows that the assessment scores are very similar to each other with no discernible difference. We can conclude that the switch to digital applications would result in no detriment to the trainees. The digital applications produced can be regarded as viable alternatives to the traditional approach. We can identify from the assessment scores that they do act as adequate teaching tools compared to the current provision whilst offering more flexibility in where and when the learning can happen. From the qualitative data collected, there are various suggestions from participants in how to improve both applications.

However, the UCD method in which the two applications were produced did not take full advantage of technology and gamification to create more engaging learning tools. Learning methods were secondary to usable design when the applications were in the design phase. Many participants felt that "the ACPO could be more like a game in parts" and that the LI application could benefit from multiple different modalities such as asking the player what the corresponding ICAO code is to the displayed location on screen rather than the other way around. Other studies which measured the learning effectiveness of gamified mobile apps found success when they utilised common gamification methods such as progress bars and badges (Ngan, et al., 2016), achievements (Su & Cheng, 2014), quizzes (Pechenkina, et al., 2017) and location based mechanics and AR (Gordillo, et al., 2013). These all use different gamification techniques to positive effect. They also consider how to present learning and consider the learning of their target user. Pechenkina, et al. integrates the mobile application with traditional classroom learning, ensuring that the mobile application focuses on the existing curriculum whilst providing an engaging experience (Pechenkina, et al., 2017). Like LI, the application produced focuses on flexibility whilst acting as a validation tool for previous classroom-based lectures. The app can also be used as a revision tool, with repeatable quizzes as well as providing motivation via badges and shared leaderboards. The application demonstrates the use of different gamification techniques to provide worthwhile learning tools which possessing multiple modalities for different learning styles.

LI and the ACPO Starter Pack both utilise gamification techniques, yet if more time had been spent on designing gamification in a meaningful way as well as focusing on user-centred design principles greater success could have been yielded. The level of learning engagement may have increased alongside assessment scores if the design had focused more on gamification. Su & Cheng based their gamified application on a 'motivational model' to provide essential motivation to users based on the theory that motivated learners are successful learners (Su & Cheng, 2014). Their study involved different participant groups using different learning tools to learn content. In the post-test, participants using the application achieved higher than the groups using the traditional learning content. Bartel and Hagel integrate student performance into the process in order to present users with tailored content. They present 'motivational areas of impact' as fundamentals of learner motivation, these include 'arouse curiosity', 'promote independence', 'adapt difficulty' and 'create incentives' (Bartel & Hagel, 2014). Both Hashim et al., and Huizenga present mobile learning applications which perform better than the equivalent traditional learning content (Hashim, et al., 2011) (Huizenga, et al., 2009). One notable difference is that within the design phase, both referenced studies consult with lecturers or high school teachers. Whilst the tenets of Dieter Rams have been considered alongside UCD principles to influence the design process, how and why learners learn, and the use of learning methods was considered lower priority than usability. Neither was the impact certain gamification techniques could have on the effectiveness of the two applications as teaching tools.

Utilisation of gamification techniques and the inclusion of learning methods in our methodology may provide future applications with better engagement and higher academic performance.

Studies which compare participants using traditional training vs gamified, mobile or other digital equivalents have proven to create more engaging and more effective learning tools (Su & Cheng, 2014 (Huizenga, et al., 2009) (Hashim, et al., 2011). One study into the teaching of language, reported that a mobile gamified version of an application was more effective than a mobile application teaching the same content without gamification (Sauerland, et al., 2015). Our study results in almost identical levels of performance from the two participant groups. It is worth reflecting that the overall assessment scores are not the complete answer. Analytics show that the knowledge of participants improved over time with the digital applications, and although the same can be said for the traditional material, with individuals of both groups learning over the test period more iteration could yield better results. The learning improvements are mirrored in the playtime over the period and the self-reported time spent reflect that participants that were more engaged and retained more. High levels of engagement are a requirement in learning any new skill or material. The main issue was that both applications were designed with an adherence to design principles over established learning techniques and did not exploit gamification techniques fully. This has possibly made for the applications being relatively engaging but not well designed for teaching. The highest performing participants from the group using the existing training utilised methods such as maps, repeated reading, word association and flashcards. Perhaps by introducing different modalities of learning through gamification, both applications can be improved to be more effective at teaching.

The two applications present two mobile learning applications which (according to assessment results) are as effective at teaching as the existing training implemented within a workplace. The two apps can be operated without any prior training and can be used on multiple different mobile devices, providing effective training to remote workers. Clear changes to improve both applications have been identified via the data collected as part of this study. Teaching the content via different methods shows that there is no detriment to the content currently being taught as participants have shown the capacity to learn a large volume of information in a short space of time. Note that participants only had a small monetary reward for motivation, this comes in stark contrast to the real-world motivation of a potential career which pays a high sum of money (National Careers Service, n.d.). In our previous study, both applications performed well, receiving high usability scores with the applications being designed with a UCD approach with significant research being conducted into the wants and needs of its target users, trainee ATCs. Participants from this study also reacted positively to the two applications with one participant stating, “It's good and interactive way to learn with (an) iPad app” and another commented “The ACPO's application was very useful and fun to use”.

6. Conclusions

Throughout the research a significant amount of knowledge has been gained from the design and testing process for developing applications for the ATC industry. The organisation the authors have collaborated with are looking to build upon the results of the research and continue to innovate their current training through gamification, user experience design and digital technology.

Due to the COVID-19 pandemic, the sample size was smaller than planned, but we feel able to draw conclusions from the data gathered. A longer study with the same materials may provide more insight into the learning effectiveness of both applications with participants being able to become significantly more familiar with the contents. Embedding analytics into the ACPO Starter Pack and making additional changes could make a replicated study valuable for the wider research area of digital learning. The analytics used were not infallible with two participants producing unusable data due to either a lack of playtime or the playstyle of participant. Concerning the time spent by participants, whilst analytics allow us to see the playtime of participants using the LI app, self-reporting by participants was the only available way to collect playtime data. Therefore, we cannot be certain that playtime was completely accurate. By cross-referencing self-reported playtime data with assessment scores throughout participants, we can ascertain that participants self-reported with a high accuracy.

This paper demonstrates the use of digital learning tools to train ATC trainees, with two applications which have undergone testing with a wide audience. The requirements to become an ATC trainee is only the most basic of qualifications, by testing with a large group of individuals with differing demographics we can gain insight into the reaction to the two apps by potential ATC recruits. With this paper we review the outcomes of the design of

two applications which have been designed with a user-centric design approach and that integrate gamification. We review this approach by evaluating the learning ability of the two apps which have been created under these criteria. M-learning represents an approach to learning underutilised to train ATCs and other air traffic services personnel (Haissig, 2013). This approach has the potential to innovate the training of ATCs and potentially other safety-critical job roles as well as make a significant impact on the efficiency and performance of work-based training.

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