The Role of Presence in Learning Household Waste Separation in Augmented Reality

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January 29, 2024

Master Thesis Human-Computer Interaction

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Acknowledgements

To preface this thesis, I would like to give special thanks to several people who have helped me author this thesis. Without their help, guidance, and/or encouragement this thesis would have likely been impossible. I am especially grateful to those around me who have taught me invaluable things I did not expect to learn while working on this thesis.

In particular, I want to express my gratitude to Nina Rosa, the supervisor of this thesis, for the guidance and patience she showed during this thesis project. I believe she went above and beyond what could be expected of a supervisor in helping me work on the thesis, lending her knowledge and expertise when I needed it, and showing a great amount of patience and empathy whenever things didn't go smoothly.

I would also like to convey great appreciation for some of the people around me in my personal life, particularly my parents, my brother and Alex, who have supported and motivated me deeply throughout this sometimes seemingly insurmountable project.

Lastly, I want to thank the participants who participated in the study. It seemed nigh impossible to find enough participants for the experiment, but many were kind enough to take time to participate in my study. Without them, this study would not have been possible.

Abstract

Proper recycling of household waste is vital for the transition towards a circular economy in which natural resources are used more sustainably. In many regions in Europe, there exists a highly efficient infrastructure for the recycling of household waste. However, a correct recycling process also involves the knowledge, behaviour, and attitude of the population which is sometimes lacking due to the lack of accessible education regarding recycling. Augmented Reality (AR) has shown promise as a novel method of providing great accessibility and improved learning within different fields of education, partly due to its ability to evoke a sense of presence within users. This study aims to investigate the relationship between learning gains, attitude towards recycling, and presence within a mobile AR learning environment along with the relationship between semantic coupling and perceived presence. An experiment was conducted among 42 students using an AR application that guides users through the recycling process of waste objects. The results of this study show that semantic coupling positively impacts the level of presence, but that presence does not have a strong effect on learning gains, only on change on attitude towards recycling. The findings suggest that strongly coupled activities are beneficial to the level of presence, and subsequently attitude change, but that the effects of presence on learning gains in AR activities might be overstated.

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1 Introduction

Excessive waste production and improper disposal of waste is a serious problem across contemporary society, and its management has become a priority for governments. Waste separation and recycling are vital for the transition towards a circular economy in which natural resources are used more sustainably [75], and in which environmental pollution by waste is minimized. Several European countries have already implemented efficient systems that rely on source-segregation of household waste [5]. Despite the underlying infrastructure and high efficiency of such systems, it is still reliant on the participation of households in the act of correctly separating waste within their personal environment. As such, the waste separation behaviour plays a key role in determining the success or failure rate of waste management. Several empirical studies have pointed out that citizens who feel indifferent to recycling or have otherwise negative attitudes towards recycling have a lower propensity to participate in recycling [77].

Research suggests that higher recycling participation may be achieved by employing communication strategies that focus on providing more information on recycling, reinforce positive attitudes towards recycling and mitigate negative attitudes [77]. Hornik et al. argue that the strongest predictors on recycling behaviours are internal facilitators, such as knowledge and commitment, with money and social pressure as external incentives are less strong predictors. An increase in information on recycling not only increases peoples' motivation to participate in recycling, but also makes separation less difficult, resulting in less incorrect use of waste containers [35]. This finding is also reflected in a research report on behaviour in waste separation in Dutch households [57], which concludes that knowledge about the different types of waste and how waste should be separated is not to be underestimated when it comes to household waste separation behaviour. Similarly, research suggests that convenience is also key to waste separation behaviour. The easier it is to understand and use waste management systems, the more likely it is to be used [42].

One novel way of providing information and education on proper waste separation, and potentially enhance recycling behaviour, is through game-based learning and gamification. Current research on the use of gamification for waste separation is scarce, but promising [69, 33, 49]. Beyond this, AR (Augmented Reality) is similarly being researched as an avenue for behavioural changes in environmental contexts [34]. The existing body of research in this particular area shows that AR is an interesting and promising approach for learning in the context of environmental issues, and promoting pro-environmental behavioural changes and attitudes [19]. The use of AR in education settings is relatively well studied, with various studies highlighting the potential benefits and advantages offered in both learning and teaching [79, 25].

While current research on mobile applications and AR within the context of waste separation approaches mostly focus on motivation and gamification, there is only a scarce amount of research looking into the learning effects and potentially interesting AR affordances and factors influencing the learning outcomes of these approaches in this context. A good understanding of different waste objects and waste separation rules is vital to throwing away waste and recycling properly. As such, the educational part of such applications is vital to their usefulness [69].

One specific area of research into the use of AR in learning is particularly interesting, presence. Presence is the sense of spatially being in a virtual environment even when the user is physically in another [65]. Research into presence in educational contexts with AR show that presence has a positive effect on learning outcomes in various contexts in education, with other research indicating that presence is also strongly related with enjoyment [15, 74]. Presence in AR, while generally observed as a beneficial factor in the use of AR, is relatively understudied in comparison to presence in Virtual Reality (VR). With AR offering different affordances there are factors unique to AR that influence the users' level of presence, such as the congruence between an activity and the location in which it takes place, known as semantic coupling [61]. Presence in both AR and VR is also of interest in regards to having a positive effect on attitudes and behaviour in the context of environmental sustainability, though empirical evidence is lacking [19].

The objective of this study is twofold. Firstly, it is to investigate the potential positive relationship between presence and learning gains within the context of a waste separation AR intervention. Secondly, it is to investigate the relationship between presence and attitude change.

Therefore, this study will try to answer the following research questions:

RQ1: *To what extent is there a relationship between presence and learning gains in the context of a mobile AR waste separation learning application?*

RQ2: *To what extent is there a relationship between presence and recycling atttiude and behaviour in the context of a mobile AR waste separation learning application?*

2 Related work

2.1 AR and Presence

Mobile AR has been described in literature as especially promising in the context of learning as mobile devices with small form factors allow for the use of educational AR anywhere at any time [76]. This proposed utility of mobile AR in learning and education is also supported by the amount of recent research within this field [31]. The main finding of a systematic review of research on mobile learning in teacher education is that mobile learning is reported as mainly beneficial due to it providing motivating factors, enhancing social interaction, among other reasons [4]. In the context of waste separation mobile AR is very interesting also, as recycling behaviour takes place in different physical locations.

To better understand the user experience and engagement in AR and its applications, research has investigated concepts that relate to the user's feelings related to being in an AR environment. One salient concept within the body of research is that of presence.

Presence can be roughly described as the feeling of "being there" in mediated environments [65] as the result of the sensory stimuli offered by AR. The definition of presence in academic literature has changed over time, as its roots lie in the world of media and emergent technologies such as telecommunications, high-definition television, and the world wide web [48]. While its definition has become more unambiguous and several models have been developed, there is no commonly agreed upon model for presence.

Presence within the context of XR is still commonly defined as the illusion of "being there" in a virtual or mixed environment. However, this concept has been explicated as AR technologies were being developed [45]. Lee argues that the psychological state of presence in AR also includes how virtual objects are perceived in sensory or cognitive ways [45]. Similarly, in the context of VR, it has also come to signify behaving in the virtual environment as in the real world [68].

The feeling of presence is closely related to other concepts within the field of AR and game research, such as immersion and flow. In some definitions of presence, immersion and presence are essentially synonymic. However, most theoretical research pertaining to these concepts deems immersion a technological factor necessary or beneficial for the presence of users [51, 44].

In terms of media characteristics, Sheridan suggested three types of determinants of presence in virtual and mixed environments: the extent of sensory information presented, the amount of control one has over the sensors in the environment, and the degree to which one can modify the environment and its objects [70]. These determinants of presence have been the foundation of several theoretical models of presence [51, 55, 65].

2.1.1 Causes and effects of presence

A recent theoretical model of learning in immersive VR highlights the importance and the benefits of presence within the context of VR [51]. This model describes that presence facilitates situational interest in the user through intense or novel environmental stimuli and that higher presence is associated with higher motivation and enjoyment [12, 59, 50]. Furthermore, Makranksy and Petersen [52] found a positive path between presence and self-efficacy, facilitated by intrinsic motivation. However, the model simultaneously describes a positive relation between presence and extraneous cognitive load, potentially hindering the user in particular tasks.

Similarly, a conceptual framework of technological affordances for AR games examined users' immersion and presence levels and investigated how these factors influence user experience [71]. The framework illustrates how immersion and presence influence empathy and embodiment, which subsequently influence playability. Simultaneously, the framework posits that immersion and presence are important antecedents of users' attitudes and behaviours. These models of presence are further supported by more recent empirical research which sought to investigate the causes and effects of presence described in theoretical literature. These empirical attempts highlight the relation between AR affordances, presence, and behaviour in virtual environments better.

One such study investigated the relationship between the types of user interface and presence within an interactive narrative AR game [36]. The results reveal that different interaction methods offered by the system influence the extent of the illusion of presence. Users with 3D Roleplaying Game experience had a higher level of presence in a system with a graphical user interface, whereas inexperienced users had a higher level of presence in a system a natural user interface. This study simultaneously confirms that presence can differ significantly per user and user group.

Steptoe et al. investigated the effects of non-photorealistic rendering on presence and embodiment, with particular interest in understanding presence and embodiment as a product of the blending of the real and virtual [73]. While their findings were inconclusive, the results of the study serendipitously supported the notion of behavioural realism being positively influenced by immersion and environmental consistency.

More recently, efforts to understand the causes of presence also include research into how narrative can affect presence. One recent study has found that a greater semantic coupling between the physical space and narrative of an AR learning activity can result in higher levels of presence and conceptual learning gains in mobile AR [26].

As such, existing research shows that presence is an important factor in the user experience of AR environments and that it is linked to several affective and cognitive factors of the users. While existing literature posits that presence is a predictor of behaviour and attitude within AR games, this is not researched extensively outside of the context of games [71]. Empirical investigation into the relation between presence, behaviour, and attitude in AR outside of games is lacking.

While existing studies have proven that affordances and particular design principles have significant impact on the users' presence in AR systems, not all are quite suitable in the context of mobile-based AR apps. Kim [40] highlights this by pointing out that immersion and presence in mobile AR are mostly based on contextual affordances, as they employ mobile and location-based interfaces and combine physical and digital spaces.

Therefore, a contextual affordance specific to AR such as semantic coupling is a most interesting avenue of enhancing presence within the context of learning waste separation.

2.2 Learning in AR

AR has proven to be a medium with much potential within the context of education, with many studies and literature reviews highlighting the potential advantages offered by the medium in both teaching and learning [79, 25, 3, 47].

Within the field of learning, several AR applications have been designed specifically for science education. Cheng & Tsai [16], in an analysis of current research in the field, examined the associations between technical features and science concepts. They found that vision-based AR is often used to support the teaching of spatial ability, practical skills and conceptual understanding. There exist several studies that investigate the use of AR in the context of inorganic chemistry [58], geosciences [39], and operational safety [24], among others. Location-based AR is often employed in studies about scientific inquiry learning, which relies on situated learning as its foundation [20]. Location-based AR is well-suited for inquiry-based learning, due to the mobility of such AR. It allows for role-playing and gaming designs that facilitate cognitive scaffolding for the learning activity, and help students develop conceptual understandings in a collaborative way [72].

One early conceptual model that attempts to address the potential relationship between presence in virtual environments and learning outcomes is the immersion, presence, performance (IPP) model [13]. This model integrates several older attempts at modelling presence and learning. The model proposes that immersion, along with the requirements of tasks, result in the allocation of resources to attention. This can in turn lead to a suspension of disbelief, which results in a heightened sense of presence in the user. The model subsequently proposes that this heightened sense is beneficial to performance, and as such there is a positive interaction between presence and performance. More recent conceptual models related to presence within both VR and AR [51, 44] retain the essence of this model, but expand on it by relating presence to learning outcomes through several affective and cognitive factors.

These conceptual models are bolstered by the findings of empirical research [15, 44, 7]. Much of this empirical research highlight the positive effect of immersion and sense of presence to learning outcomes in various scientific contexts within K12 education. Furthermore, research has also indicated that presence and immersion are strongly related with enjoyment [74].

However, high levels of presence, especially in the context of mobile-based AR activity, should not be taken for granted, as it is often difficult to achieve and maintain [53]. In mobile-based AR learning activities especially, there are various external distractions, hardware issues and context-related factors that might impede the sense of presence [21, 22]. As mentioned before, semantic coupling is an interesting avenue of enhancing presence utilizing contextual affordances.

2.3 Semantic Coupling

The theoretical basis for semantic coupling have their roots in design guidelines for the creation of situated mediascapes, designed location-aware experiences that are enabled by mobile devices [61]. In these guidelines, Reid et al. argue that coupling between real-world spaces and narrative may have an impact on immersion in mobile-based activities. This coupling is a measure of the extent to which there is a meaningful connection between a physical space and a mediated narrative experience.

To decide how important a location will be to a situated mediascape, Reid et al. distuingish between three levels of significance to a place: (a) *Arbitrary linkage*, in which the place is arbitrary, solely used as a physical area that could be anywhere geographically. Reid et al. use an analogy of a stage or a dance mat; it is simply a surface that is required to contain the mediascape. (b) *Physicality* is the level at which places have particular features that are semantically significant, but in which the geography is not relevant. This implies that the mediascape could be remapped on to any geographical location that has the same set of features, such as particular objects. (c) *Particular location*, the third level at which the physical location and artefacts within a space are significant and meaningful to the mediated experience. As such, mediascapes based on historical events should take place at the actual location of the events. Reid et al. also investigated the relation between immersion and strong coupling between narrative events and the physical place in which it took place [62]. The findings of this study indicate that experiences with moments of strong coupling resulted in a more immersive experience.

Motivated by Reid et al.'s characterization [61], Karapenos et al. [38] argue that there are two distinct forms of locality in mobile-based activities: (a) *Orginal location*, where the activity takes place at the location that is most directly related to the given narrative and that contains physical cues from the narrative, and (b) *Same atmosphere*, in which the activity takes place in a location that only resembles the original location through physical elements such as lighting and noise conditions. Karapenos et al. simultaneously found that a condition based on the higher level of coupling between place and narrative had a positive impact on the immersion of the users. However, no significant difference in the users' presence was found between two conditions based on these levels of locality. Though strong coupling between space and narrative seems preferred, Rossitto et al. [66] found in an evaluation of a location-based audio drama that loose coupling enables users' imagination, as users develop their own meaningful associations between elements of the space and elements of the narrative.

More recently, Georgiou & Eleni [27] investigated the effects of the different levels of coupling of narrative and locality on immersion, presence and learning gains in an AR learning activity. Furthermore, main factors that affect students' immersion, flow and presence for each type of semantic coupling were identified. The findings of this research indicate that strongly-coupled AR activities facilitate higher levels of presence, and improve students' learning gains. These findings are aligned with Reid's argument of enhanced presence in activities in which the place and narrative are strongly related [61], as well as with Cheng & Tsai's assumption that perceived presence of a learner relates to the behaviour of learners in AR-related learning [16].

Taking into account that existing research on the relation between semantic coupling and presence provides ample evidence that semantic coupling of the location and the activity has an effect on presence in the context of AR, it becomes interesting to also investigate this relationship within the context of an AR waste separation learning application.

3 Methodology

To answer the research question of this study, an experiment was conducted in which participants interacted with a mobile AR application designed to teach users how to properly separate waste and recycle through feedback, Augcycle.

3.1 Augcycle

Augcycle is the mobile AR application that was used for this experiment. The application was designed to teach basic underlying rules of household waste separation through feedback. As of conducting this study, no openly available application such as this existed, and so it had to be designed and developed specifically for this study. The main goal of Augcycle is to assist the user with correctly throwing away waste objects on a case-by-case basis, with general underlying recycling rules being taught to the user through textual feedback. The application is marker-based and prototypically uses markers to identify both waste objects and bins.

In terms of functionality, Augcycle is relatively basic. The application prompts the user to hold a waste object in front of the device's camera. Scanning a waste object's QR-like marker, a small virtual 3D object will appear as an indicator. Scanning a recycling bin marker shows a virtual platform above the recycling bin. Upon holding the object indicator above a type of recycling bin, the application shows an overlaying text with feedback on whether or not the object belongs in that bin. This feedback expands also on the exact reasoning as to why the object belongs, or does not belong, in that particular bin.

The feedback given by Augcycle is based on a decision tree synthesized from recommendations, guidelines and instructions from Afvalscheidingswijzer [14]. This decision tree covers most possible waste objects, and can be used to identify the correct bin for waste objects for which the correct bin might not be obvious.

3.2 Participants and design

The study is designed as a between-subjects study to minimize the possible effects of learning and transfer across conditions. The study had two conditions, related to the semantic coupling of the location and the activity of separating waste: a strongly coupled condition, and a loosely coupled condition. For both conditions, the activity involving Augcycle was the same. However, the two conditions were conducted in two different locations, of which the semantic coupling would differ. Participants were assigned to one of the two conditions based on the time and day of participation. Participants were recruited through convenience sampling on the Utrecht University campus. In total, 42 participants (21F, 21M) took part in the on-location experiment. Ages ranged from 18 to 29 (M=22). All participants were students studying at Utrecht University at the time of participation. The experiment in its entirety took about 30 minutes to complete per participant.

3.3 Procedure

Upon giving consent and admitting voluntary participation, the participants were first asked to give demographic information. Afterwards, they were asked to fill in a questionnaire measuring their attitudes and intentions towards recycling.

Upon filling in the questionnaire, the participants were prompted to use Augcycle on a provided mobile device, a OnePlus Nord CE 2 Lite, to throw away 12 different waste objects in a random order. The list of waste objects was the same for both conditions. The items were chosen based on their level of perceived difficulty, which was discerned through a small pre-study in which people were asked to rate waste objects by their difficulty. For each object, the participant had a choice of 6 recycling bins (Paper, PMD, Glass, General Waste, Turn-In, GFT/Organic), which were physically situated next to each other at the location of the experiment. Each bin had at least one associated waste object, with the waste objects covering all of the decisions of the aforementioned decision tree. Participants were given no time limit for this activity.

After completing the waste separation activity using Augcycle, the participants were again asked to fill out several questionnaires. Again, their attitudes and intentions towards recycling were measured. Perceived presence and immersion were measured using the ARI questionnaire [28], which focuses on location-awareness, engagement and immersion. Next to this, the participants had to perform a post-test in which they had to indicate in which bin another 12 waste objects would go, similarly to the waste separation activity. These waste objects were different from the ones used during Augcycle, but involved the same rules and difficulty level. Participants were shown images of the 12 waste objects, and gave both their choice and their reasoning on a laptop with none of the objects physically present.

Additionally, the participants were asked to fill in the System Usability Scale questionnaire to roughly measure Augcycle's usability [10]. Lastly, participants filled out an original 3-item questionnaire about their experiences and feelings towards the space in which the experiment took place in the context of the waste separation activity. This questionnaire could validate whether or not the locations were, as assumed, strongly and loosely coupled. This questionnaire can be seen in Table 1. Afterwards, the participants were given a chance to give comments about the application and the experiment. These comments won't be analysed extensively in this study, but could be used to explain certain findings.

Please indicate how much you agree with the following statements	Strongly disagree				Strongly agree
I often throw away waste in this type of space	o	o	o	o	o
I associate this type of space with waste separation	o	o	o	o	o
The physical space of the activity is connected to the waste separation theme of the activity	o	o	o	o	o

Table 1: Original semantic coupling questionnaire

Between the two conditions there was only one difference, namely the location. The two locations for these conditions, as shown in Figures 1 and 2, were chosen based on how strongly coupled they were semantically to the activity. Because semantic coupling of location and activity can differ between groups

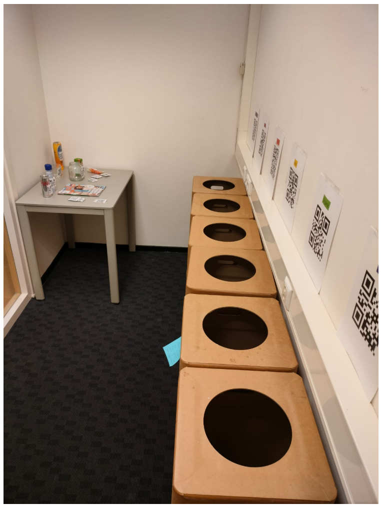


Figure 1: The small conference room, as the loosely coupled location

Figure 2: The university building hallway, as a strongly coupled location

of people, a small pre-study involving informal conversations with students on campus was conducted to find suitable locations that would be particularly strongly or loosely coupled to the activity. Based on these conversations, university building hallways were strongly coupled due to there being many recycling bins and students frequently throwing waste away in this location. Conference rooms, in particular small conference rooms, were identified as a location in which students rarely ever recycle or connect to the theme of waste separation. Due to the noisy nature of the university building hallways, the experiment was conducted at times where the hallways would be relatively calm and free of potential distractions affecting the process or outcome of the experiment.

3.4 Measures

3.4.1 Presence and immersion

Presence, and more broadly immersion, was measured using the AR Immersion (ARI) questionnaire [28]. This 21-item, 7-point Likert-type questionnaire was specifically designed and validated with measuring immersion in AR location-aware contexts and location-based AR. This questionnaire was factored, but no instructions on how to analyse the results of the questionnaire was found. Therefore, this scale was tested for reliability using Cronbach's alpha.

3.4.2 Recycling attitudes

The variable of recycling attitudes was measured using a short 6-item Likert-type instrument on a scale from 1 to 7 (completely disagree - completely agree), with items such as 'I find the idea of recycling pleasing', and 'I am not interested in the idea of recycling'(reversed). These items were based on prior usage of this instrument within similar research [43].

3.4.3 Recycling intentions

To measure recycling intentions, for each type of waste (paper, glass, plastic, general waste, compostables, electronics, small chemical waste, waste with deposit), participants were asked to rate how likely it was for them to either recycle or otherwise sort during the next month. Ratings were made on a 7-point scale

(Extremely unlikely - extremely likely). The mean of these ratings were taken as the global measure of recycling intention.

3.4.4 Learning gains

The dependent variable learning gains was measured using the answers given by the participants during the use of the Augcycle application and the answers given in the post-test. Both the pre- and post-test included 12 items. The pre-test scores were taken from the answers participants gave while using Augcycle. For each object they would give a correct answer on the first try, 2 points were given. No points were given for objects for which the participant had given an incorrect answer. The post-test also required users to explain the reasoning behind their answers. This was done so that it was possible to identify whether the participant had learnt or otherwise understood the underlying rules of recycling. Because of this, this reasoning was taken into accounting for the post-test scoring as well. 1 point was given for each correct answer, with 1 point being given if the reasoning behind the answer was in line with the rules from the decision tree that were taught in Augcycle. No points were given if the wrong bin was chosen and no such reasoning was given.

3.5 Data analysis

In order to process the learning gains data from the study, the scores from the pre- and post-test had to be calculated. Before any analysis could be done, the test scores had to be determined using a rubric, as described above. Additionally, to come to the variables needed for the data analysis, Cronbach's alpha factor analyses were performed on the questions on presence (a = .890), the recycling attitudes questionnaire (a = .934), the recycling intention questionnaire (a = .864) and the semantic coupling validation questionnaire (a = .928). With a small number of participants per condition, most of the distributions differing significantly from the norm, and treating the Likert scale data as ordinal, nonparametric tests were used for analysis.

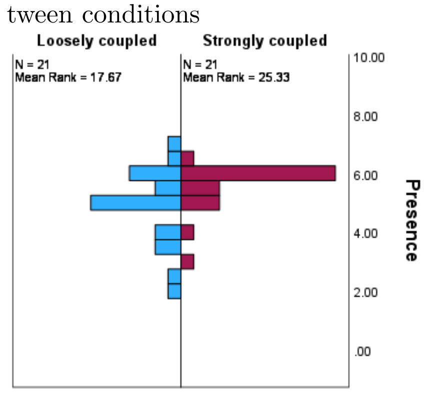
4 Results

Based on the literature and research questions, the three hypotheses of this study are as follows:

H1: *The semantically strongly coupled group will have a higher level of presence than the semantically loosely coupled group*
H2: *Presence is positively correlated with learning gains*
H3: *Presence is positively correlated with change in recycling attitude and intended behaviour*

The data from the questionnaire was analyzed using a Mann-Whitney U test between the dependent *Presence* variable and the *conditions*. This test reveals that there is a significant difference in presence between the two conditions, U = 301.00, p = .036. The output of the test can be seen in Figure 3, where it can also been seen that there are a few ties between the two conditions, and the level of presence is relatively high for both conditions.

Figure 3: The distribution of medians of *presence* between conditions



To more closely investigate this difference, Mann-Whitney U tests were performed between the individual *Presence* questions and the *conditions*. The results of these texts can be found in Table 2 Using Bonferroni correction, the desired significance level is a = .0125.

Spearman's rank correlation was computed to assess the relationship between *Presence* and *Learning gains*. There was no significant correlation found between the two variables, r(40)= .116, p = .463

To assess the relationship between *Presence* and *Recycling attitudes*, a Spearman's rank correlation was used. A moderate positive correlation was found between the variables, r(40) = .460, p = 0.002. The same was done for *Recycling intentions*. A weak positive correlation was found between *Presence* and *Recycling intentions*, r(40) = .305, p = 0.049.

A Mann-Whitney U test was performed to evaluate whether the validation questions differed by *condition*. The results indicate there is a significant difference between the results of the validation questionnaire of the two *conditions*, U = 421.00, p ¡ .0001.

The System Usability Score was calculated using the scoring system provided by Brooke [10]. According to this system, Augcycle scores just above average based on the average scores between the participants (M = 69.70, SD = 1.48). With this score, it can be reasonably assumed that Augcycle does not have major usability issues interfering with the rest of the results.

Question	p value	Null Hypothesis
”The activity felt so authentic that it made me think that the virtual objects existed for real.”	.083	Retain
”I felt that was I was experiencing was something real, instead of a fiction activity.”	.052	Retain
”I was so involved in the activity, that in some cases I wanted to interact with the virtual objects directly.”	.010	Reject
”I so involved, that I felt that my actions could affect the activity.”	.145	Retain

Table 2: Mann-Whitney U test results between presence statements and the condition

5 Discussion

5.1 Semantic Coupling and Presence

One of the aims of this study was to investigate the impact of semantic coupling of the location and the AR activity would have a positive effect on the feeling of presence of the user. The results of this study showed that, generally, the level of presence was higher in the strongly coupled condition than in the loosely coupled condition. Upon closer investigation, only one question differed significantly between these conditions. There was also a difference between conditions for the other questions as well, though not significant. These results indicate that the semantic coupling of the location and the AR activity does significantly impact the level of presence of the user. This is in line with findings of similar research [26, 18], and the theoretical papers [60, 61] describing the potential benefits of semantic coupling. Likewise, these findings contradict the previous literature favouring loosely coupled AR activities [38].

One thing of note is that from the analysis, the largest statistical difference between the conditions can be seen in the participants wanting to interact directly with the virtual objects more in the strongly coupled activity. Though the results give no direct clue as to why this question was answered more positively in the strongly coupled condition group than the other questions in comparison to the loosely coupled condition group, it is possible that participants found the physical action of throwing an item into the bin to be more natural or intuitive in a location that usually contains physical bins and thus saw the bins, including the virtual outlines, as more of interactable objects. In this sense, the bins could double as a physical cue related to the activity [60].

5.2 Presence and Learning gains

Another aim of the study was to investigate the potential relationship between presence and learning gains. The findings from the analysis of the data suggest that there is no significant relationship between the level of presence of the user and their learning gains. The absence of such a significant relationship between these two variables contradicts some of the findings of similar research [28, 26, 67] and prior assumptions [16] about this relationship. A significant relationship between presence and learning gains in this study can be ascribed to several factors.

Firstly, it is possible that the time for which the participants interacted with Augcycle was too short to solidly grasp the underlying rules of recycling on which the feedback was based, and which the participants were expected to apply in the post-test. Though research on learning new information on mobile devices exists [8, 4], it is difficult to estimate what amount of time one would need to spend interacting with a learning application before they understand and can apply new recycling rules. Augcycle did not measure the time participants spent looking at the screen or reading the feedback, and it is possible that some participants only briefly looked to see if the feedback message was green or red. Likewise, the relative short length of the entire experiment could also have had an impact on the relationship between presence and attitude change.

Secondly, a potential reasoning for these findings can be that the participants did not answer the post-test questions only using what they had learnt during the AR activity. In the post-test participants gave some reasonings that much more resembled their preconceived knowledge or conceptions about how to recycle objects than the rules taught through feedback from the application. For example, a few participants would argue that an empty can of shaving cream would wrongly go into the general waste bin, as 'it is a mix of materials', even though Augcycle taught the user that this kind of can contains propellants, which do not belong in that bin. Similarly, a participant's reasoning for putting a greasy pizzabox wrongly into the paper bin was 'I know it's dirty, but it's still going into my paper bin'. These reasonings indicate that not every participant used the rules taught by Augcycle to answer the post-test.

5.3 Presence and Recycling attitudes

The third aim of this study was to investigate if there was a relationship between presence and the recycling attitudes of participants. The analysis shows that there is a moderate positive correlation between presence and the recycling attitudes measured in the post-test questionnaire. Considering the previous finding of presence having no significant positive relationship with learning gains this is an interesting finding, as there was an assumption that an increase in learning gains would subsequently lead to an increase in recycling attitudes based on theoretical literature [77]. It is possible that, in this case, participants with a higher level of presence were simply more engaged with the experiment as a whole and thus more engaged with the topic of recycling and sustainable behaviour. Though this level of engagement was not measured on the scale of the experiment and thus this possibility can not be confirmed, it is similar to the reasonings of literature on engagement and recycling and environmental attitudes [23, 64]. Similarly, the analysis shows that there is a weak positive correlation found between presence and recycling intentions for which the reasoning above also applies.

5.4 Limitations

Despite this study's contribution to a better understanding of semantic coupling and the relationship of presence on learning gains and attitude change in AR learning applications, there were certain important limitations that should be noted alongside the study's results.

Due to logistical and practical constraints, it was not feasible to perform the experiment outside of the university campus. In the context of household waste separation, there are some locations that would be more strongly coupled than possible on the university campus. From the pre-study leading to the choice of locations, the most strongly coupled location seemed to be one's own kitchen, and the least coupled location would be a forest or a car. Had these locations been used instead, it is possible that the difference in presence would be larger.

One other limitation is that of the operationalization of learning gains in this study. In the study, learning gains were measured by taking the answers given by the participants at the pre-test, and comparing those to those of the post-test, which included reasoning behind answers. Alongside the aforementioned issue of participants sometimes giving reasonings that were unrelated to the rules taught by Augcycle, but arguably correct and sound in practice it is possible that participants were basing their answers and reasoning on their local recycling rules. This effect could be mitigated by phrasing the post-test differently.

This study was approached only with a quantitative method, with only some optional final comments from the participants. For some of the quantitative findings, it would have been useful to have more qualitative data for a better understanding of certain quantitative findings. For example, it would have been good to know exactly how participants experience the virtual objects, apart from wanting to interact with them, or viewing them, as physical objects.

Measuring the participants' level of presence was done through a self-report questionnaire. With little other options to measure presence and the questionnaire being a good fit in terms of context, this was a good approach. Despite this, one could argue that measuring presence after the activity and through self-reports is a limitation in of itself. Further research could look into using different approaches to measure presence, such as psychiological responses [54].

The AR activity seemed to only have a minor impact on the participants' intention to recycle. One of the participants' comments hints as to why this might be. Even if one were to learn how to recycle properly or find more motivation to engage in recycling behaviour from using the application, it would not always change their ability to recycle properly as the local facilities available to that person might be insufficient to do so. Due to the wording of the questions regarding their intent, it is possible this did not negate all possible increases in recycling intentions. However, a more complete questionnaire on the participants' intent to recycle would give more insight into potential benefits here.

Despite the positive outcome of the usability test of Augcycle, it is possible that Augcycle ultimately fell short in terms of the communication methods it employs or its perceived usefulness. Due to the scope of this study, it was not feasible to conduct a pre-study to test the system for such issues, or to iteratively design Augcycle specifically for this.

6 Conclusion

Current literature on these topics suggest that a strong semantic coupling of the location and the AR activity has a positive effect on presence, which subsequently has a positive effect on learning. Additionally, literature suggests that a better understanding of waste separation rules contributes to more positive attitudes and intentions towards recycling and that AR offers an interesting approach to teaching such knowledge. As such, the study presented in this paper was motivated by the goal of gaining a better understanding of semantic coupling, presence and learning in AR in the context of a waste separation learning application. The results of this study show that there is a positive effect of semantic coupling on presence, with a significant increase in presence in a strongly coupled scenario over a loosely coupled scenario. However, the results also show that this increase in presence is not positively correlated with the learning gains in the context of learning waste separation through an AR activity. Despite this, there was a significant correlation between presence and recycling attitude, indicating that higher levels of presence do contribute to attitude change in AR learning activities.

With these findings, the study provides empirical evidence for some of the claims made in theoretical papers on the effect of semantic coupling on presence and its benefits in AR learning activities and applications, with some caveats. The results indicate that the level of semantic coupling between physical space and the type of AR activity has a positive effect on the level of perceived presence, as in line with prior claims [61, 38] and studies [26, 18]. Also, higher levels of presence are associated with a more positive change in recycling attitudes. However, contradicting these prior claims, it seems that a higher level of presence does not lead to higher learning gains in the context of AR learning activities. While there is a strong case to make for more strongly coupled AR activities in the context of AR learning applications with the findings of both this study and prior studies, the findings of this study also indicate that the effect of presence on learning gains within this context might be overstated, and should be investigated further. As prior studies were done with more narrative-based AR activities, it is possible that this positive effect of presence on learning gains is stronger in AR activities with a strong narrative. This is an interesting blind spot in the current body of literature, and warrants further empirical research.

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7 Annotated appendix

7.1 Preliminary literature study

This is a preliminary literature study written as part of the research proposal for this thesis. Though not all of this literature from this review was used in the paper, it covers some related topics alongside the main topics..

7.2 Literature review

7.2.1 Household recycling and environmental attitudes

Excessive waste production and improper disposal of waste is a serious problem across contemporary society, and its management has become a priority for governments. Waste separation and recycling are vital for the transition towards a circular economy in which natural resources are used more sustainably [75], and in which environmental pollution by waste is minimized. Several European countries have already implemented efficient systems that rely on source-segregation of household waste [5]. Despite the underlying infrastructure and high efficiency of such systems, it is still reliant on the participation of households in the act of correctly separating waste within their personal environment. As such, the waste separation behaviour plays a key role in determining the success or failure rate of waste management. Several empirical studies have pointed out that citizens who feel indifferent to recycling or have otherwise negative attitudes towards recycling have a lower propensity to participate in recycling [77].

Research suggests that higher recycling participation may be achieved by employing communication strategies that focus on providing more information on recycling, reinforce positive attitudes towards recycling and mitigate negative attitudes [77]. Hornik et al. [35] argue that the strongest predictors on recycling behaviours are internal facilitators, such as knowledge and commitment, with money and social pressure as external incentives are less strong predictors. An increase in information on recycling not only increases peoples' motivation to participate in recycling, but also makes separation less difficult, resulting in less incorrect usage of waste containers. This finding is also reflected in a research report on behaviour in waste separation in Dutch households [57], which concludes that knowledge about the different types of waste and how waste should be separated is not to be underestimated when it comes to household waste separation behaviour. Similarly, research suggests that convenience is also key to waste separation behaviour. The easier it is to understand and use waste management systems, the more likely it is to be used [42].

One novel way of providing information and education on proper waste separation, and potentially enhance recycling behaviour, is through game-based learning and gamification. Current research on the use of gamification for waste separation is scarce, but promising [69, 33, 49]. Beyond this, augmented reality is similarly being researched as an avenue for behavioural changes in environmental contexts [34]. The existing body of research in this particular area shows that augmented reality is an interesting and promising avenue for learning in the context of environmental issues, and promoting pro-environmental behavioural changes and attitudes [19].

To further examine the potential of augmented reality in the context of teaching waste separation rules, a taxonomy of types of AR is given and the most suitable types of AR are discussed. Particular affordances, together with presence as a characteristic of augmented reality related to learning and attitude adjustment, are also discussed. Furthermore, semantic coupling design principles are examined as a potential avenue for enhancing presence.

7.2.2 Augmented Reality

Throughout the existing body of research, AR has been defined diversely. Milgram et al. [56] defined augmented reality as both "augmenting natural feedback to the operator with simulated cues" and "a form of virtual reality where the participant's head-mounted display is transparent, allowing a clear view of the real world." These definitions reflect the early state of AR technology, which included only head-mounted displays that could impose virtual information onto the real world. Azuma [2] defined AR in a much broader fashion, claiming that AR encompasses the systems that fulfil three essential features: the combination of real and virtual worlds, interaction in real-time, and accurate 3D registration of virtual and real objects. More recently, AR has been defined in a broader sense as AR is no longer limited to any particular technology such as head-mounted displays [78]. Displays for AR often encompass video see-through, optical see-through, projection-based systems, or a combination of those [29].

Milgram's Virtuality Continuum [55] visualizes the mixture of classes of objects presented in any particular display situation. This visualization of the virtuality of environments reveals that environments exist on a spectrum, ranging between purely real to purely virtual. AR is positioned somewhere along the middle of this spectrum, indicating a combination of both real and virtual objects and places. Milgram simultaneously provides a formalised taxonomy for mixed reality that includes the users' knowledge of the world they perceive in mixed reality, how realistic the world is being displayed and mixed reality hardware, and the extent of presence metaphor.

With advances in computer technology, there exists more hardware and software that can be utilized for AR. In particular, handheld computing has opened many new avenues for AR and has subsequently spawned a subset of AR that utilizes the affordances of mobile devices, mobile AR [80]. Next to making AR potentially more ubiquitous, mobile AR allows for location-based or -aware and pervasive AR applications [9].

Apart from mobile AR, there can also be made a distinction between two primary types of AR, location-based and vision-based AR [37]. Vision-based AR utilizes physical triggers that the AR device recognizes and are linked to virtual information or media, which the AR device will then display. Oftentimes, these physical triggers include distinctive pictures, QR codes and other markers such as logos. Location-based AR instead utilizes the GPS capabilities of mobile devices to embed virtual information and media in particular locations. Due to the location-awareness of such systems, it is also possible for these systems to superimpose virtual elements onto real-world objects or places. These two primary types of AR rely on different affordances of AR devices and have different use cases. In AR learning environments, it is important to align the instructional and learning approaches with the type of AR environment. The different types of AR support different learning strategies based on their affordances [78].

Location-based learning scenarios within AR emphasize the affordances of mobile devices to deliver information about the physical environment of the user. In doing so, AR can immerse users by blending the real-world spaces with virtual information that can augment learning and engagement [41]. The educational benefits associated with learning in location-based AR include collaborative problem-solving, inquiry-based simulations and interactions with virtual agents [30].

Vision-based AR utilize AR visualizations overlaid on the real world, and real-world objects. This allows users to be more immersed and interact with virtual information that is superimposed unto the environment or physical objects [20]. This immersive interactive learning, used together with portable devices, allows users to better learn at their own pace [17]. This flexibility has a positive effect on the experience of learners and the acquisition of skills required in workplace settings [63].

Mobile AR has been described in literature as especially promising in the context of learning as mobile devices with small form factors allow for the use of educational AR anywhere at any time [76]. This proposed utility of mobile AR in learning and education is also supported by the amount of recent research within this field [31]. The main finding of a systematic review of research on mobile learning in teacher education is that mobile learning is reported as mainly beneficial due to it providing motivating factors, enhancing social interaction, among other reasons [4]. In the context of waste separation mobile AR is very interesting also, as recycling behaviour takes place in different physical locations.

To better understand the user experience and engagement in AR and its applications, research has investigated concepts that relate to the user's feelings related to being in an AR environment. One salient concept within the body of research is that of presence.

7.2.3 Presence

Presence can be roughly described as the feeling of "being there" in mediated environments [65] as the result of the sensory stimuli offered by AR. The definition of presence in academic literature has changed over time, as its roots lie in the world of media and emergent technologies such as telecommunications, high-definition television, and the world wide web [48]. While its definition has become more unambiguous and several models have been developed, there is no commonly agreed upon model for presence.

Within the context of these emergent technologies, Lombard and Ditton argue that presence is that a perceptual illusion of non-mediation [48]. According to Lombard and Ditton, this illusion occurs when a person can no longer perceive or acknowledge that they are interacting through a technological medium. There have been several attempts to distinguish between different types of presence to better understand the underlying mechanics of presence [32, 6, 65]. The most salient taxonomy of presence is that of Ijsselsteijn & Riva, who identify two broad categories of presence - physical and social. Because presence is considered a perceptual illusion and is related to cognitive processes and psychological factors, it is something that varies across individual users and across time for the same individual user [65].

Presence within the context of AR is still commonly defined as the illusion of "being there" in a virtual environment. However, this concept has been explicated as AR technologies were being developed [45]. Lee argues that the psychological state of presence in AR also includes how virtual objects are perceived in sensory or cognitive ways [45]. Similarly, it has also come to signify behaving in the virtual environment as in the real world [68].

The feeling of presence is closely related to other concepts within the field of AR and game research, such as immersion and flow. In some definitions of presence, immersion and presence are essentially synonymic. However, most theoretical research pertaining to these concepts deems immersion a technological factor necessary or beneficial for the presence of users (Makransky, 2021;Kye, 2008).

In terms of media characteristics, Sheridan suggested three types of determinants of presence in virtual environments: the extent of sensory information presented, the amount of control one has over the sensors in the environment, and the degree to which one can modify the environment and its objects [70]. These determinants of presence have been the foundation of several theoretical models of presence [51, 55, 65].

7.2.4 Causes and effects of presence

A recent theoretical model of learning in immersive VR highlights the importance and the benefits of presence within the context of VR [51]. This model describes that presence facilitates situational interest in the user through intense or novel environmental stimuli and that higher presence is associated with higher motivation and enjoyment [12, 59, 50]. Furthermore, Makranksy and Petersen [52] found a positive path between presence and self-efficacy, facilitated by intrinsic motivation. However, the model simultaneously describes a positive relation between presence and extraneous cognitive load, potentially hindering the user in particular tasks.

Similarly, a conceptual framework of technological affordances for AR games examined users' immersion and presence levels and investigated how these factors influence user experience [71]. The framework illustrates how immersion and presence influence empathy and embodiment, which subsequently influence playability. Simultaneously, the framework posits that immersion and presence are important antecedents of users' attitudes and behaviours. These models of presence are further supported by more recent empirical research which sought to investigate the causes and effects of presence described in theoretical literature. These empirical attempts highlight the relation between AR affordances, presence, and behaviour in virtual environments better.

One such study investigated the relationship between the types of user interface and presence within an interactive narrative AR game [36]. The results reveal that different interaction methods offered by the system influence the extent of the illusion of presence. Users with 3D RPG experience had a higher level of presence in a system with a graphical user interface, whereas inexperienced users had a higher level of presence in a system a natural user interface. This study simultaneously confirms that presence can differ significantly per user and user group.

Steptoe et al. investigated the effects of non-photorealistic rendering on presence and embodiment, with particular interest in understanding presence and embodiment as a product of the blending of the real and virtual [73]. While their findings were inconclusive, the results of the study serendipitously supported the notion of behavioural realism being positively influenced by immersion and environmental consistency.

More recently, efforts to understand the causes of presence also include research into how narrative can affect presence. One recent study has found that a greater semantic coupling between the physical space and narrative of an AR learning activity can result in higher levels of presence and conceptual learning gains in mobile AR [26].

As such, existing research shows that presence is an important factor in the user experience of AR environments and that it is linked to several affective and cognitive factors of the users. While existing literature posits that presence is a predictor of behaviour and attitude within AR games, this is not researched extensively outside of the context of games [71]. Empirical investigation into the relation between presence, behaviour, and attitude in AR outside of games is lacking.

While existing studies have proven that affordances and particular design principles have significant impact on the users' presence in AR systems, not all are quite suitable in the context of mobile-based AR apps. Kim [40] highlights this by pointing out that immersion and presence in mobile AR are mostly based on contextual affordances, as they employ mobile and location-based interfaces and combine physical and digital spaces.

Therefore, a contextual affordance such as semantic coupling is the most interesting avenue of enhancing presence within this context. While there are currently no existing design guidelines for semantic coupling in vision-based AR described in literature, there is enough theoretical literature to synthesize design guidelines for semantic coupling in vision-based AR. This study will include an attempt at creating such guidelines, as well as validating these guidelines.

7.2.5 Learning in AR

AR has proven to be a medium with much potential within the context of education, with many studies and literature reviews highlighting the potential advantages offered by the medium in both teaching and learning [79, 25, 3, 47].

AR, and especially immersive AR, can foster and facilitate educational experiences that include authentic contexts and activities, which are requirements of situated learning [21]. The situated learning theory posits that all learning takes place within a specific context and the quality of learning is a product of the interactions between entities, processes, and culture within that context [11]. At its simplest, situated learning is learning that takes places in the same, or a similar, context in which the knowledge or skills are applied

[46]. AR, which facilitates immersive learning experiences, therefore offers a great potential advantage; the simulation of real-world problems and contexts fosters near-transfer of skills and knowledge, allowing learners to more easily apply what they have learned in the real world [20].

Situated learning is not often employed in educational settings. This relatively unstructured form of learning is difficult to arrange due to prohibitive cost and managerial challenges associated with bringing students into complex real-world settings. AR enables the arrangement of such learning by allowing learners to interact with virtual entities which are designed specifically for learning within a context that resembles the real-world setting [21].

Within the field of learning, several AR applications have been designed specifically for science education. Cheng & Tsai [16], in an analysis of current research in the field, examined the associations between technical features and science concepts. They found that vision-based AR is often used to support the teaching of spatial ability, practical skills and conceptual understanding. There exist several studies that investigate the use of AR in the context of inorganic chemistry [58], geosciences [39], and operational safety [24], among others. Location-based AR is often employed in studies about scientific inquiry learning, which relies on situated learning as its foundation [20]. Location-based AR is well-suited for inquiry-based learning, due to the mobility of such AR. It allows for role-playing and gaming designs that facilitate cognitive scaffolding for the learning activity, and help students develop conceptual understandings in a collaborative way [72].

Similarly, Wu [78] provides an overview of instructional approaches and AR features and affordances. In this overview, five affordances based on research that utilizes AR for educational purposes are described: (1) Learning content in 3D perspectives, (2) ubiquitous, collaborative and situated learning, (3) learners' sense of presence, immediacy, and immersion, (4) visualizing the invisible, and (5) bridging formal and informal learning. Wu et al. argue that these affordances should be aligned with instructional approaches that emphasize roles, locations or tasks.

One early conceptual model that attempts to address the potential relationship between presence in virtual environments and learning outcomes is the immersion, presence, performance (IPP) model [13]. This model integrates several older attempts at modelling presence and learning. The model proposes that immersion, along with the requirements of tasks, result in the allocation of resources to attention. This can in turn lead to a suspension of disbelief, which results in a heightened sense of presence in the user. The model subsequently proposes that this heightened sense is beneficial to performance, and as such there is a positive interaction between presence and performance. More recent conceptual models related to presence within both VR and AR [51, 44] retain the essence of this model, but expand on it by relating presence to learning outcomes through several affective and cognitive factors.

These conceptual models are bolstered by the findings of empirical research [15, 44, 7]. Much of this empirical research highlight the positive effect of immersion and sense of presence to learning outcomes in various scientific contexts within K12 education. Furthermore, research has also indicated that presence and immersion are strongly related with enjoyment [74].

However, high levels of presence, especially in the context of mobile-based AR activity, should not be taken for granted, as it is often difficult to achieve and maintain [53]. In mobile-based AR learning activities especially, there are various external distractions, hardware issues and context-related factors that might impede the sense of presence [21, 22]. As mentioned before, semantic coupling is an interesting avenue of enhancing presence utilizing contextual affordances.

7.2.6 Semantic Coupling

The theoretical basis for semantic coupling have their roots in design guidelines for the creation of situated mediascapes, designed location-aware experiences that are enabled by mobile devices [61]. In these guidelines, Reid et al. argue that coupling between real-world spaces and narrative may have an impact on immersion in mobile-based activities. This coupling is a measure of the extent to which there is a meaningful connection between a physical space and a mediated narrative experience.

To decide how important a location will be to a situated mediascape, Reid et al. distuingish between three levels of significance to a place: (a) *Arbitrary linkage*, in which the place is arbitrary, solely used as a physical area that could be anywhere geographically. Reid et al. use an analogy of a stage or a dance mat; it is simply a surface that is required to contain the mediascape. (b) *Physicality* is the level at which places have particular features that are semantically significant, but in which the geography is not relevant. This implies that the mediascape could be remapped on to any geographical location that has the same set of features, such as particular objects. (c) *Particular location*, the third level at which the physical location and artefacts within a space are significant and meaningful to the mediated experience. As such, mediascapes based on historical events should take place at the actual location of the events. Reid et al. also investigated the relation between immersion and strong coupling between narrative events and the physical place in which it took place [62]. The findings of this study indicate that experiences with moments of strong coupling resulted in a more immersive experience.

Motivated by Reid et al.'s characterization [61], Karapenos et al. [38] argue that there are two distinct forms of locality in mobile-based activities: (a) *Orginal location*, where the activity takes place at the location that is most directly related to the given narrative and that contains physical cues from the narrative, and (b) *Same atmosphere*, in which the activity takes place in a location that only resembles the original location through physical elements such as lighting and noise conditions. Karapenos et al. simultaneously found that a condition based on the higher level of coupling between place and narrative had a positive impact on the immersion of the users. However, no significant difference in the users' presence was found between two conditions based on these levels of locality. Though strong coupling between space and narrative seems preferred, Rossitto et al. [66] found in an evaluation of a location-based audio drama that loose coupling enables users' imagination, as users develop their own meaningful associations between elements of the space and elements of the narrative.

More recently, Georgiou & Eleni [27] investigated the effects of the different levels of coupling of narrative and locality on immersion, presence and learning gains in an AR learning activity. Furthermore, main factors that affect students' immersion, flow and presence for each type of semantic coupling were identified. The findings of this research indicate that strongly-coupled AR activities facilitate higher levels of presence, and improve students' learning gains. These findings are aligned with Reid's argument of enhanced presence in activities in which the place and narrative are strongly related [61], as well as with Cheng & Tsai's assumption that perceived presence of a learner relates to the behaviour of learners in AR-related learning [16].

Taking into account that existing research on the relation between semantic coupling and presence provides ample evidence that semantic coupling of the places and the AR experience has an effect on presence in the context of location-based AR, it becomes interesting to also investigate this relation within the context of vision-based AR. Currently, no guidelines exist for semantic coupling in vision-based AR. Such guidelines would be beneficial to forming a better understanding of how to design vision-based AR learning experiences. As such, this study aims to create and validate a set of guidelines specifically for vision-based AR learning experiences.

7.3 Augcycle

In this section, Augcycle is described in more detail than done so in the paper of thesis due to the length restriction of the paper. Also, the design process behind Augcycle is covered in more detail.

The code repository of Augcycle can be found here.

7.3.1 Description of Augcycle

Augcycle is the mobile AR application that was used for the study. The application was designed to teach basic underlying rules of household waste separation through feedback. As of conducting this study, no openly available application such as this existed, and so it had to be designed and developed specifically for this study. The main goal of Augcycle is to assist the user with correctly throwing away waste objects on a case-by-case basis, with general underlying recycling rules being taught to the user through textual feedback. The application is marker-based and prototypically uses markers to identify both waste objects and bins.

In terms of functionality, Augcycle is relatively basic. The application prompts the user to hold a waste object in front of the device's camera. Scanning a waste object's QR-like marker, a small virtual 3D object will appear as an indicator. Scanning a recycling bin marker shows a virtual platform above the recycling bin. Upon holding the object indicator above a type of recycling bin, the application shows an overlaying text with feedback on whether or not the object belongs in that bin. This feedback expands also on the exact reasoning as to why the object belongs, or does not belong, in that particular bin.

The feedback given by Augcycle is based on a decision tree synthesized from recommendations, guidelines and instructions from Afvalscheidingswijzer [14]. This decision tree covers most possible waste objects, and can be used to identify the correct bin for waste objects for which the correct bin might not be obvious.

The application also logs the users' actions by creating new files containing data. This logging was required to get data from the experiment.

7.3.2 Technical details

Augcycle was developed using Unity 2023.2.1, utilising Unity's AR Foundation framework for the Augmented Reality capabilities. For the experiment Augcycle was ran on a OnePlus Nord CE 2 Lite, on Android version 13.

7.3.3 Limitations

Unfortunately, during the development and implementation of Augcycle, a few limitations came up. The biggest one is that ARCore, Android's framework for Augmented Reality, did not support image recognition from 30cm away from the camera. This was an issue that hindered the development of Augcycle significantly, especially as this issue was not immediately obvious. Due to the issue arising later down development of the application, it was not possible to utilise a different framework, such as Vuforia Engine. To combat the issue, the intended way in which the user interacts with the physical objects and the bins had to be changed. Unfortunately, this resulted in the users having to manually scan the bins every time they wanted to throw something away, as well as keep the camera close to the marker. Some participants during the experiment remarked that this interaction felt a little awkward.

7.3.4 Design process

Augcycle was designed using several design techniques. The application had to fulfill a few core requirements. Augcycle had to:

- Be able to recognize waste objects and bins
- Give feedback based on the users' choice of bin per item
- Save data about the users' choices during the experiment
- Instruct the user on how to interact with the application

With these requirements, several storyboards were created to get a better idea of how such an application would be used by a real user. These can be found in Figures 4 through 7.

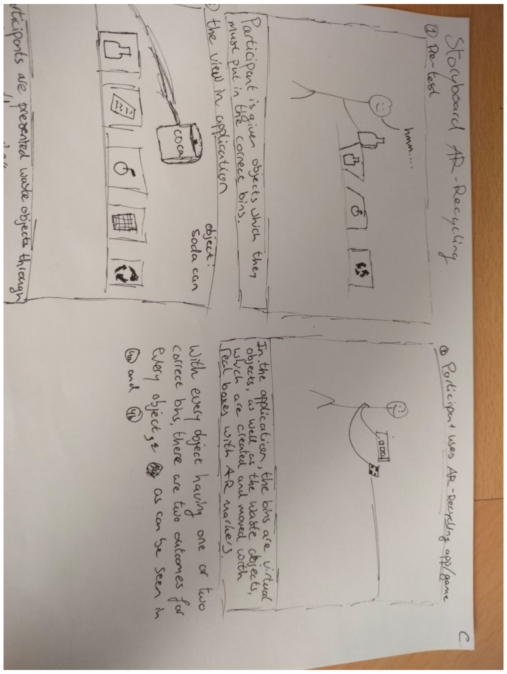

Figure 4: Part 1 of the storyboard

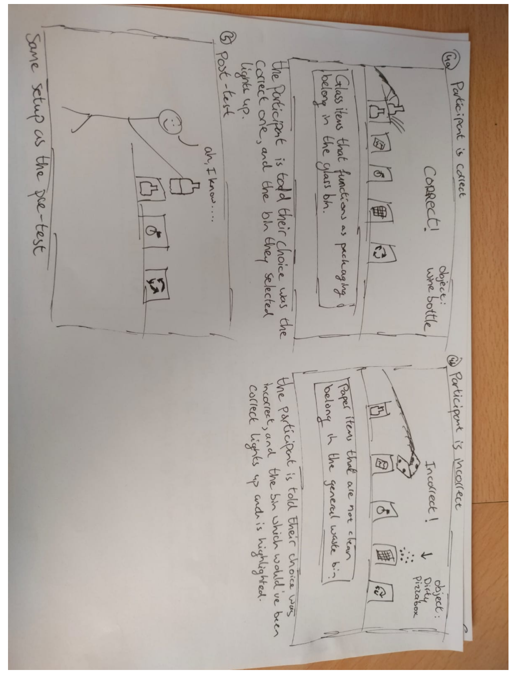

Figure 5: Part 2 of the storyboard

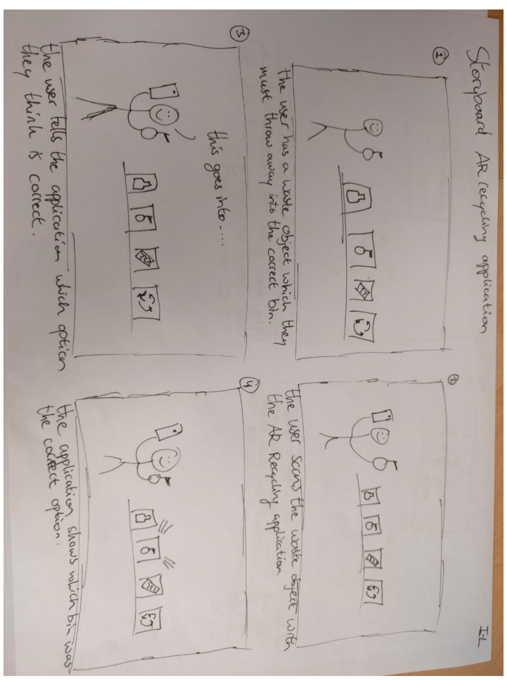

Figure 6: Part 3 of the storyboard

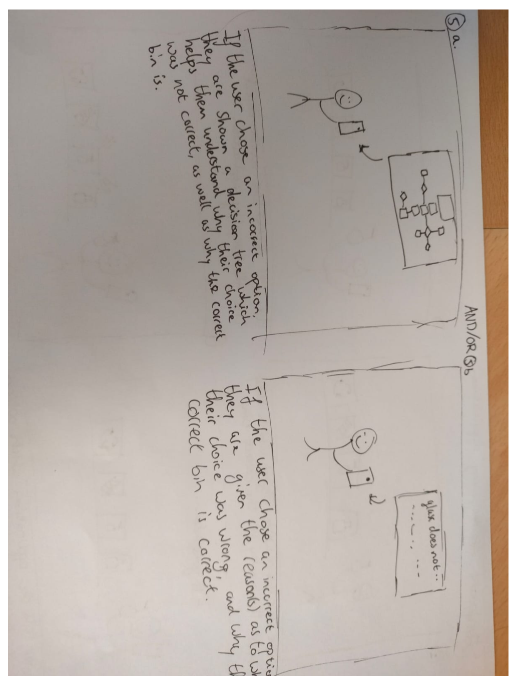

Figure 7: Part 4 of the storyboard

In addition to the storyboards, two persona's were created to better account for different kinds of learning approaches in the design of the application. These persona's were based on preliminary interviews about potential requirements. The interviews and the persona's based on these interviews can be found below.

Interviews

Interviewee 1: 25F

A young student who finds herself environmentally conscious but admits to having consumption habits bad for the environment, mostly buying a lot of clothes. Recently moved from home and has started living with her boyfriend, so she is still trying to figuring out how to manage a household. Considers herself to produce a lot more waste, mostly food and clothing related. Food waste was surprising to her, as she only recently started cooking meals from scratch (vegetables in plastic, etc.) Tries to recycle and separate everything right at home. She thinks it is ultimately good for the environment because less plastics, glass etc. have to be made from new raw materials. Also doesn't find it that big of a deal to figure it out. She does not consider herself very knowledgeable about recycling other than the 'basics'. She occasionally struggles with separating waste properly with things she herself never had to throw away before, things like glass and batteries, but is otherwise fine without any assistance. Sometimes struggles with her boyfriend not sharing her commitment to throwing things away properly. Also finds it difficult to 'manage' the green waste bin in their household. She doesn't produce much 'green' waste, and finds that it often starts smelling after a while. At university, she tries to separate everything properly, and she finds that her university facilitates this quite well. She does not have to throw away waste often outside. When asked about separating waste for recycling in other places, she says that it is usually impossible to do. Thinks bins, at home and elsewhere, could do with some illustrations, or text on them to explain in more detail what goes in there, and how to properly recycle some of the articles that go into that bin.

Interviewee 2: 51M

Find himself environmentally conscious and makes an active effort to reduce waste and footprint wherever possible. Works in the packaging/logistics industry and is knowledgeable about the packaging of household products. Since working in that industry, he has looked very differently at the waste he produces and has changed his lifestyle to try to produce as little waste as possible. Understands the complexity of recycling, especially of packaging containing different kinds of plastics. Also thinks that recycling is simply too difficult for most people; the systems behind it are so complex that most people don't have the time to be brought fully up to speed about everything that is involved. Still, finds properly separating waste important. He does not struggle much with separating most of his waste, but occasionally has to use Google to find out in which bin specific things go, especially electronics. Separating his waste has become a habit, and his local municipality has an easy-to-use application to see when waste gets picked up. He is quite content with this app, and thinks local municipalities can play an important role in making recycling properly easy for people. Outside of the house, he finds that there are very little ways to properly separates waste. He thinks this is logical, because many people do not throw away very much individually when outside of their homes. However, he believes that the amount of unseparated waste this ultimately produces is much larger than most people expect. Thinks labels on packaging should be much more informative, especially plastic packaging that contain different kinds of plastics. He argues that this will help in two ways; people will be better at separating their waste, but will also be much more aware of what packaging is particularly bad or good for the environment. Also thinks that local municipalities should make more effort in informing inhabitants about proper recycling.

Interviewee 3: 21F

Finds it difficult to be interested in recycling or being 'overly' environmentally conscious, because he believes his behaviour does not matter much in the grand scheme of things. He believes most of the environmental responsibility lies with governments and big polluters in industries. He does try to comply with the recycling laws, but finds the rules needlessly complicated. He also finds it unlikely that separating waste actually contributes to anything, he believes most of the waste will end up in 'the same pile' anyway. However, he admits that he is not very well educated on the topic of recycling. He thinks he produces a ‘normal’ amount of waste. He compares his amount of waste with that of his housemates, who (according to him) produce much more waste than he does. Most of the waste he produces is food related. The main difficulties he faces when separating his waste are with the things he does not have to often throw away, such as batteries and electronics. He also admits to not knowing very well what goes into the green waste bin when cooking. When he is in doubt, this waste often ends up in the general waste bin. Outside of the house, he sometimes finds it easier to recycle: the garbage bins at his university and workplace are separated by type of waste and have good visual indications of what must go in. This makes it easy to separate the waste that he produces in those places. He finds it kind of motivating to recycle when it is made so simple and easy for him. Thinks an ‘afvalscheidingswijzer’ app could be useful to give people near-immediate instructions on how to recycle everything.

Interviewee 4: 35F

She is a working mother in her mid-thirties, and she is quite ambivalent about the environment; she is not ‘overly concerned’ or ‘obsessed’ with it but sees sustainable behaviour as a personal responsibility. She finds it important that the world her child will live in is one that is healthy and sustainable. However, she does not have much free time in which she can really educate herself or make any big lifestyle changes. Considers herself to produce quite a lot of waste on a household level and mentions that having a young child does make it extremely difficult to reduce waste. She finds separating waste properly important, but sometimes finds it quite difficult to do so. She thinks that being in a certain rhythm and having certain habits makes it much easier, because you pretty much only deal with waste that you have dealt with before. She relates this to the waste that her child produces, which has changed over the years and has made properly recycling quite a challenge sometimes. She tries to make it much easier for herself by looking up information on how to separate waste and hanging this information on an easily visible place in the kitchen. One difficult item to recycle in particular is dirty food packaging, which she still does not really know how to recycle properly sometimes. Outside of the house, she finds separating waste extremely difficult. There are little opportunities for her to do so, as all garbage bins at her workplace are not separated. She has not put much thought into it, but considers it a missed opportunity that her workplace is not more facilitative in this regard. She believes education to be extremely important when it comes to recycling and other sustainable behaviour. According to her, the younger generations have a much better idea of how to live sustainably and separating waste in the future will be easier to them.

Persona 1

Anna, 36F

Anna has recently had her first child. This has made her more environmentally conscious, as she wants to make the world a better place for her recently born child. However, Anna finds it difficult to act environmentally conscious in her everyday life, especially with a new member in her household. Because Anna is in charge of many of the household tasks and chores, she is often the one to sort the household’s waste. She has done this for some time, but never gave much thought to whether she was separating waste correctly. Anna is not very knowledgeable about waste separation and recycling, and also needs to know how to deal with waste related to her baby. With the recent change in her thinking about the environment, she wants to change this by better understanding how she can contribute to a circular economy by changing her own waste separation behaviour. With her newborn child, Anna does not have much spare time to spend looking for information. Despite this, Anna wants to find resources that educate her on how to separate waste properly. She has often thought about attending talks, lectures, and such in person. However, she finds it difficult to find the time to leave her house for such events.

Goals:

- Educate herself, and eventually her child, on how to separate waste and recycle properly.
- Be more knowledgeable about recycling processes.

- Be able to run the household efficiently.

Frustrations:

- Is not very tech savvy, does not use her phone much throughout the day.
- Does not have much free time to go to events outside of her home.

Persona 2

Frank, 28M

Frank has recently moved out of his parents' house, together with his partner. While living at his parents, Frank did not often have to separate waste as this was often done by his parents. Because of this, Frank does not understand how to separate waste very well. He and his partner often get into small arguments over how a particular waste object should be thrown away. While Frank is not very environmentally conscious, he wants to separate waste properly. With many waste objects at home, Frank has a vague idea of where it should go, but often has doubts about it. To free himself from doubt, he does an extremely quick Google search from which he will accept the first result. Frank often does this for many things he needs guidance for. More recently, Frank must do this quite often as he deals with many new objects to throw away. Because of this, Frank is looking for resources that can guide him to better separate his waste, beyond the simple Google searches that frequently give contradicting results.

Goals:

- Quickly identify the correct way of throwing away waste objects.
- Spend as little effort and time as possible on these chores.

Frustrations:

- Often gets into discussions about where waste should go.
- Does not want to spend much effort.
- Dislikes the contradicting results of Google searches.

Ultimately, the design of Augcycle is mostly based on the second persona, as it was more fitting to create an application that could teach basic recycling rules anywhere at anytime for this study. Had the study been longitudinal, Augcycle would likely have been more designed around the first persona.

7.4 Recycling decision tree

To operationalize the participants' understanding of recycling rules, a recycling decision tree was made. This decision tree was created so that the rules and the feedback given by Augcycle could be more structured. The decision tree is based on information found on the Dutch Afvalscheidingswijzer website [14], which contains information about many different types of waste objects and how they should ideally be recycled. More specifically, the decision tree is based on the information given about particular waste types, and on information given on specific waste objects. The decision tree was designed iteratively, going through informal user testing to see if the decision tree made sense to potential users. The decision tree can be found in Figure 8.

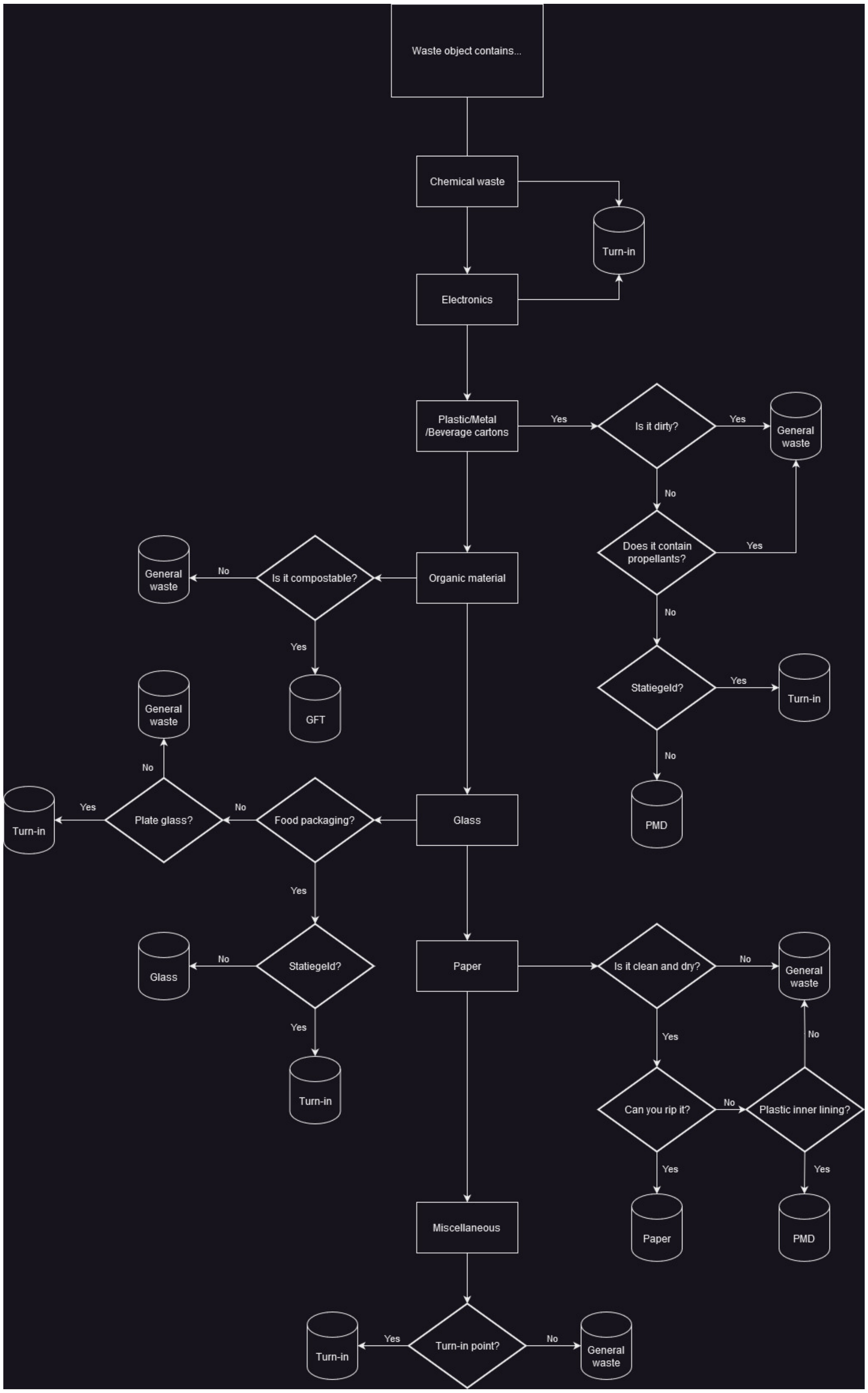

Figure 8: The recycling decision tree

7.5 Waste objects

In Table 3, the full list of waste objects used for this experiment can be found. This list of waste objects was created through iteratively going through several lists of household waste items. The items were chosen in such a way that there were differing levels of difficulty, based on informal conversations and user testing. The items were chosen so that during the experiment, the participants would interact at least once with each bin. Additionally, between the pre- and post-test items the items were chosen based on the relative likeness in terms of related recycling rules from the decision tree, as well as a similarity in difficulty between the items.

Pre-test item	**Correct bin**	**Post-test item**
Tea bag	GFT	Coffee pod
Magazine	Paper	Newspaper
Empty can of deodorant	General waste	Empty can of shaving cream
Aluminium foil	PMD	Empty chips bag
Empty can of coke	Turn-in (Deposit)	Empty plastic water bottle
Empty bottle of nail paint	Glass	Empty wine bottle
Half-full paracetamol strip	Turn-in (Chemical)	Bucket of paint
Plastic coffee cup	PMD	Milk carton
Half-full bottle of mayonnaise	General waste	Bucket of mouldy yoghurt
Wooden ice lolly stick	General waste	Frying fat
Drinking glass	General waste	Window glass
Wet tissue	General waste	Greasy pizzabox

Table 3: The full list of objects used in the experiment

7.6 Questionnaires

Here, the questionnaires used in the methodology of this study are briefly described, as well as the reasoning behind choosing these questionnaires. This is followed by a full list of the questions and statements of these questionnaires.

7.6.1 Recycling attitudes and behaviour

To measure the participants' attitude towards recycling, as well as their intended recycling behaviour, there are no validated scales that fit the context of this experiment. Therefore, these two variables were measured using a scale based on scales used in previous research on recycling attitudes and behaviour [43] and [1], respectively. For the experiment, these scales were used both before and after the participant had interacted with Augcycle.

7.6.2 Augmented Reality Immersion questionnaire

To measure the participants' level of presence, the Augmented Reality Immersion (ARI) questionnaire [28] was used. This questionnaire was really the only reasonable option in terms of already existing scales, as it was validated and designed specifically to measure presence among immersion, engagement, enjoyment in mobile AR activities. It contains 21 items which are divided in subscales. Unfortunately, no instructions on how to analyse the data from this scale was given in the paper of this scale. As such, an original approach was taken in this regard.

7.6.3 Post-test

As part of the experiment, participants were instructed to indicate in which bins 12 different waste items would go, as well as give their reasoning textually.

7.6.4 System Usability Scale

Despite ARI also containing a subscale for usability, a more broad and elaborate scale to measure usability with was chosen alongside the other questionnaires, as it would give more insight into how the participants perceive Augcycle in terms of its usability. A low score of the System Usability Scale (SUS) would indicate that perhaps the usability issues of Augcycle had a significant impact on the results or the outcome of the study.

7.6.5 Final remarks

At the end of the experiment, the participants were able to leave some final remarks on the application or the experiment as a whole.

7.7 Full questionnaire

7.7.1 Introduction text & Consent form

The purpose of this study is to gain insight into how Augmented Reality can be utilized to enable people to recycle more and better. Before the study begins, you will be asked to fill out a questionnaire about your attitude towards recycling. During the study, you will be interacting with an augmented reality app that provides immediate feedback when recycling. Afterwards, you will be asked to fill out another questionnaire and a few other questions.

Any results gathered from this study may be used for publication, but will be fully anonymized. Taking part in the study is entirely voluntary and you may withdraw from the study at any time for any reason or no reason at all.

If you have any questions before or after the study, please contact me via k.devos3@students.uu.nl.

In order to participate in the study, please read the statements below and confirm you have read and understood these statements. Thank you.

- I confirm that I am 18 years of age or over.
- I confirm that the study has been explained to me. I have had the opportunity to ask questions about the study and have had these answered satisfactorily. I had enough time to consider whether to participate.
- I understand that even if I agree to participate now, I can withdraw at any time or to refuse to answer any question with any consequence of any kind.
- I understand that my participation in this study is completely anonymous.
- I understand that fully participating in the study will take around 30 minutes in total to finish.
- I consent to allow the fully anonymized data to be used in future publications and other scholarly means of disseminating the findings from the research project.
- I understand that the data acquired will be securely stored by researchers, but that appropriately anonymized data may in future be made available to others for research purposes. I understand that the University may publish appropriately anonymized data in appropriate data repositories for verification purposes and to make it accessible to researchers and other research users.

7.7.2 Demographics

Please select your gender

- ○ Male
- ○ Female
- ○ Other

Please fill in your age

7.7.3 Attitudes

Please indicate how much you agree with the following statements

	Strongly disagree						Strongly agree
I find the idea of recycling distasteful	○	○	○	○	○	○	○
I find the idea of recycling pleasing	○	○	○	○	○	○	○
I am not interested in the idea of recycling	○	○	○	○	○	○	○
I find the idea of recycling unpleasant	○	○	○	○	○	○	○
My feelings towards recycling are favourable	○	○	○	○	○	○	○
My feelings about recycling are positive	○	○	○	○	○	○	○

7.7.4 Intented Behaviour

Please rate how likely you are to recycle or sort waste items of the following types during the next month

	Extremely unlikely						Extremely likely
Paper	○	○	○	○	○	○	○
Glass	○	○	○	○	○	○	○
Plastic	○	○	○	○	○	○	○
General waste	○	○	○	○	○	○	○
Compostable	○	○	○	○	○	○	○
Electronics	○	○	○	○	○	○	○
Small chemical waste	○	○	○	○	○	○	○
Items with deposit (statiegeld)	○	○	○	○	○	○	○

7.7.5 Experiment prompt

Before answering the following questions, please interact with the Augmented Reality application as instructed by the researcher.

7.7.6 ARI

Please indicate how much you agree with the following statements

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
I liked the activity because it was novel	○	○	○	○	○	○	○
I liked the type of the activity	○	○	○	○	○	○	○
I wanted to spend the time to complete the activity successfully	○	○	○	○	○	○	○
I wanted to spend time to participate in the activity	○	○	○	○	○	○	○
It was easy for me to use the AR application	○	○	○	○	○	○	○
I found the AR application confusing	○	○	○	○	○	○	○
The AR application was unnecessarily complex	○	○	○	○	○	○	○
I did not have difficulties in controlling the AR application	○	○	○	○	○	○	○
I was curious about how the activity would progress	○	○	○	○	○	○	○
I was often excited since I felt as being part of the activity	○	○	○	○	○	○	○
I often felt suspense by the activity	○	○	○	○	○	○	○
If I were to be interrupted, I would have looked forward to returning to the activity	○	○	○	○	○	○	○
Everyday thoughts and concerns faded out during the activity	○	○	○	○	○	○	○
I was more focused on the activity rather on any external distraction	○	○	○	○	○	○	○
The activity felt so authentic that it made me think that the virtual objects existed for real	○	○	○	○	○	○	○
I felt that what I was experiencing was something real, instead of a fictional activity	○	○	○	○	○	○	○
I was so involved in the activity, that in some cases I wanted to interact with the virtual objects directly	○	○	○	○	○	○	○
I was so involved, that I felt that my actions could affect the activity	○	○	○	○	○	○	○
I didn't have any irrelevant thoughts or external distractions during the activity	○	○	○	○	○	○	○
The activity became the unique and only thought occupying my mind	○	○	○	○	○	○	○
I lost track of time, as if everything just stopped, and the only thing that I could think about was the activity	○	○	○	○	○	○	○

7.7.7 Post-test

Greasy pizzabox

- ○ Green bin
- ○ PMD bin
- ○ Paper bin
- ○ Glass bin
- ○ General waste bin
- ○ Waste recycling point, or other

Please explain your choice.

7.7.8 SUS

Please indicate how much you agree with the following statements

	Strongly disagree				Strongly agree
I think that I would like to use this system frequently	○	○	○	○	○
I found the system unnecessarily complex	○	○	○	○	○
I thought the system was easy to use	○	○	○	○	○
I think that I would need the support of a technical person to be able to use this system	○	○	○	○	○
I found the various functions in this system were well integrated	○	○	○	○	○
I thought there was too much inconsistency in this system	○	○	○	○	○
I would imagine that most people would learn to use this system very quickly	○	○	○	○	○
I found the system very cumbersome to use	○	○	○	○	○
I felt very confident using the system	○	○	○	○	○
I needed to learn a lot of things before I could get going with this system	○	○	○	○	○

7.7.9 Semantic Coupling validation questions

Please indicate how much you agree with the following statement

	Strongly disagree				Strongly agree
I often throw away waste in this type of space	○	○	○	○	○
I associate this type of space with waste separation	○	○	○	○	○
The physical space of the activity is connected to the waste separation theme of the activity	○	○	○	○	○

7.7.10 Final remarks

Q10.1

Do you have any other remarks or comments regarding the application or the study?

7.8 Post-test Rubric

In order to be able to score the answers participants give on the post-test, a rubric had to created to do so in a structured fashion, as well as consistently.

The way both the pre- and post-test were scored was by giving participants points based per correctly thrown away item. Because the post-test included textual reasoning, participants were given only 1 point per item correctly thrown away, and additional point for a correct reasoning. This was done so that the participants showed that they had understood the underlying recycling rules taught by the application. For each correctly thrown away item in the pre-test 2 points were given. Below, in table 4, the rubric can be found.

Object	**Correct bin**	**Line of reasoning**
Coffee pad	GFT	It is fully compostable
Bag of chips	PMD	Contains plastic/metal/aluminium
Newspaper	Paper	Fully made out of clean, dry paper
Bucket of paint	Turn-in	Contains chemicals, is considered KCA
Wine bottle	Glass	Fully made out of glass
Can of shaving cream	General waste	Contains propellants
Frying fat	General waste	Organic, but not compostable
Plastic water bottle	Turn-in	Deposit
Greasy pizzabox	General waste	Paper but too dirty
Window glass	General waste	Technically glass, but is not easily recycleable
Milk carton	PMD	Has a laminated plastic layer
Bucket of yoghurt	General waste	Plastic packaging that is too dirty/full

Table 4: The rubric used to assign points to the post-test results