Addressing Waste Separation With a Persuasive Augmented Reality App

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Separating and recycling waste is an important topic to protect our environment and achieve a more sustainable future. However, recycling also is a complex process, as each type of waste needs a specific recycling method. This comes along with multiple recycling containers, each relevant for one specific type of waste. Ensuring a correct recycling process therefore not only requires specific infrastructure, but also a respective attitude and knowledge of the population. Stressing the need for an accessible educational opportunity addressing waste separation, we present a mobile Augmented Reality (AR) application that guides a user through a recycling process and hence scaffolds the learning of proper recycling of each type of waste. The app further provides a prototypical implementation of a product scanner, that identifies the waste type based on a marker and assists the recycling on a case-by-case decision. Using self-determination theory as a framework, we integrated gamification elements, aiming for enhanced need satisfaction, motivation and user experience. In a user study, we compared the gamified version to a control version, with both app versions yielding a high acceptance, user experience, and waste separation behavior. This indicates the importance of providing easy-to-use mobile apps allowing for a learning and assistance of proper recycling.

CCS Concepts: • **Applied computing → Interactive learning environments**.

Additional Key Words and Phrases: technology-supported learning, augmented reality, sustainability, gamification

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1 INTRODUCTION

Recycling of materials is undoubtedly critical from an environmental but also from an economical standpoint. The obstacles to achieve recycling for all materials, which could be reused are diverse and highly dependent not only on infrastructure, but also on the mindset of the respective population, as

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well as their knowledge on how to recycle correctly if they are willing and if the infrastructure is in place. Several European countries and especially Germany and Sweden have been highly successful in establishing recycling programs and educating their citizens to partake in waste separation with 90% participation rate [53, 57]. However, even though Germany is generally considered a good example for recycling, there is still demand for better separation of waste to improve this process [53]. This requires addressing not only the motivation to recycle and to improve knowledge to correctly separate waste, but also to supply help in case of a perceived gap in knowledge.

Using gamification is one possibility to attain this goal in countries, which already have an underlying support infrastructure, not only as an abstract idea but as direct result of interest within the population [26]. Several approaches have already been used in different contexts to introduce a gamified approach into waste separation. This includes gamified online learning activities, such as crafting during online supervision [10]. Mobile applications have also been used to introduce an element of gamification into recycling. Current approaches can be used on community level and even include real rewards, e.g. blockchain based lotteries for families participating in recycling activities [21]. A more individual approach has been demonstrated by Aguiar-Castillo et al. [2] using an app in a region with high tourism to promote sustainable behavior. As combination of an individual approach to interact with virtual waste in combination with public displays, Centieiro et al. [8] developed a mobile application, which promoted recycling for virtual objects based on location data and subsequent interaction on a public display. However, this approach is not connected to actual recycling behavior and depends on previously set up objects and displays.

While current mobile app approaches already aim to increase motivation to recycle, they are rather limited when it comes to guiding users to recycle properly. A correct waste separation requires an understanding of the different types of waste and their respective waste containers. For instance, people often struggle to correctly dispose waste when it is made of different compounds or plastic [60]. To solve this problem, a mobile app shall not only create an incentive for recycling, but also provide general information on waste types and assist in a case-by-case decision. While the former goal could be achieved with interactive learning exercises, the latter part can easily be integrated by scanning a product's barcode and subsequently displaying recycle recommendations using Augmented Reality (AR) technology. When combined with gamification, this approach would present the recycling process in a more meaningful way by keeping a focus on the main objective [3], thus further increasing the motivation to recycle [26]. Such an approach might help to further improve recycling rates, even in countries with already high participating rate, simply because the necessary and specific information is directly available.

2 RELATED WORK

2.1 Educational Mobile (AR) Applications

To ensure an accessible format for educating about waste separation, mobile applications, e.g. on tablets or smartphones, can be suitable. They allow for an anywhere-anytime learning approach [19] and have already been integrated in education, covering various topics [58, 61]. A review by Haßler et al. [25] also rated mobile applications to be suitable to support the learning process. Mobile applications advantages include access at any time, versatility, adaptability [42]. This might be especially useful in scenarios where users need a simple and fast way to get a specific information, such as correctly recycling particular types of waste. Additionally, mobile apps might enhance the motivation of users [58, 59].

Traditional educational mobile applications can be supplemented by AR components, serving as an extension of reality [4]. As defined by Azuma [4], AR combines virtual elements with reality, providing an interactive experience in real time, anchored in 3D-space. In an educational context, the integration of AR applications can benefit the learning gains and motivation of learners. [5]. As noted in a review by Radu [39], AR supplemented applications can lead to a better understanding of learning content when compared to books, videos or computer applications, and benefit long-term knowledge retention. The review [39] also indicated positive effects of AR on performance in physical tasks regarding accuracy and transfer learning. AR applications also often provide collaboration opportunities between users [34, 39], which is used in various fields, e.g. history and heritage [38] or special needs education [56]. In addition, positive effects on the motivation of user of AR applications have been demonstrated [39]. Because these applications allow for different interactions with the system, they create more exploration opportunities and varied user experiences [5]. All these advantages of integrating AR and the wide range of possible applications demonstrate the suitability of AR for the educational context, facilitating different teaching approaches.

However, handling AR applications can be difficult and some learners might even experience negative impact on learning outcomes [5, 39, 50]. Therefore, integrating AR in applications requires thoughtful approaches identifying content where learning is facilitated by AR presentation.

2.2 Motivation and Self-Determination Theory

Self-determination theory established a close connection between motivation and the satisfaction of three basic psychological needs, namely competence, autonomy and relatedness [12]. The theory proposes a continuum for motivation ranging from extrinsic motivation to intrinsic motivation, with identified and intrinsic motivation as most self-determined and therefore most autonomous motivation. If the three basic needs are satisfied in a given context, so called internalisation of motivation is predicted to occur, which not only results in maintenance of the current motivation but instead causes integration of extrinsic motivation, resulting in a shift to more autonomous motivation within the continuum [12]. Therefore, initially extrinsic motivated behavior, can be internalised to a degree in which it is autonomously maintained [11]. An application with the aim to increase autonomous motivation should therefore convey a sense of fulfillment for competence, autonomy and relatedness [13].

Separate of the continuum, self-determination theory also describes the state of amotivation in which need satisfaction is not expected to result in a change in the motivational state [12]. A motivational change away from amotivation would therefore require a different approach, e.g. for the current context, in regard to countries with high skepticism regarding waste separation.

2.3 Gamification

Gamification is often defined as the implementation of game-specific elements in non-game contexts [16] with the aim to enhance the motivational state of learners [18]. This approach is especially common in a diverse range of E-learning environments [9, 23, 27] with a focus on language acquisition [14, 40].

Even though initial research has not always been grounded in theory, as outlined by reviews of Seaborn et al. [54] and Nacke et al. [35], more recent work often relies on the framework of self-determination theory (e.g. [1, 46, 51]).

Within a recent meta-analysis on gamification in learning [47] an overall positive effect of gamification could be demonstrated, differentiating between cognitive, motivational and behavioral outcomes. Even though the specific factors, which contribute to successful gamification are not yet clearly identified and require further research [47], some mechanisms appear to be more effective for different outcomes.

Based on the design approach for successful integration of gamification by Aparicio et al. [3], which stresses that the main goal of any application has to be maintained and gamification mechanisms should only be integrated to supplement this aim, a set of core functions for the application have to be determined, before ideas for gamification (e.g. for waste seperation [26]) can be integrated.

If integrated adequately, specific gamification elements should positively influence the basic psychological needs outlined by self-determination theory [46]. Such proposed links between gamification elements and the three basic psychological needs are presented in Table 1. To assess if the integration of the respective gamification elements results in such an effect, an experimental comparison is required [54].

Table 1. Selection of gamification elements linked to specific psychological needs.

Psychological need	Associated gamification element
Autonomy	Choice of task order [6]
	Contextual embedding [46]
Competence	Visual tracking of progress [6, 17, 45, 46]
	Visually appealing game elements [32]
	Positive feedback [6, 17, 45, 46]
Relatedness	Interaction with virtual characters [43]
	Narrative with a relevant role for the user [43, 46]

3 CONTRIBUTION

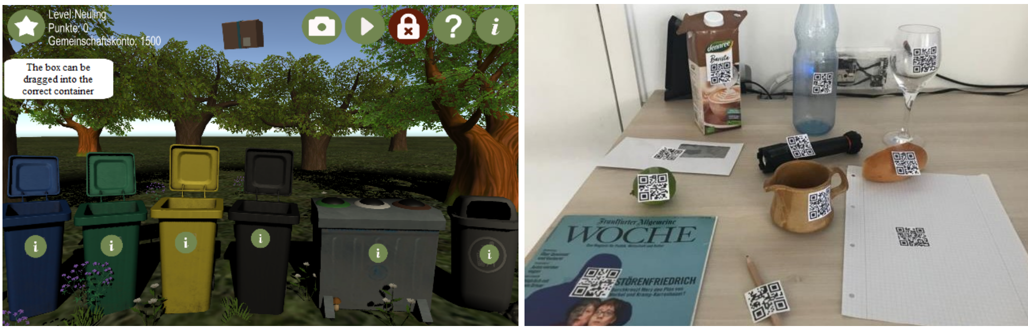
In this manuscript we describe the conceptualization, integration and evaluation of a mobile application prototype, which not only conveys precise recycling instructions based on QR-codes, but also integrates AR techniques within a narrative framework to combine recycling with gamification. For the evaluation we assess whether a basic version of the application can successfully address need satisfaction, motivational aspects and user experience. An overall positive evaluation would indicate, that this QR-code based approach could be easily extended from a prototype version to an app within an applied setting using barcodes to serve as an assistive tool in recycling decisions. Furthermore, an enhanced version, which incorporates additional gamification mechanisms is compared to the basic version to determine if these gamification elements result in additional benefits in the initial measures or even influence environmental attitudes and prospective waste separation behavior.

Our study therefore aims to address these three research questions:

- RQ 1: Is the basic version prototype suited to address need satisfaction, motivation and user experience?
- RQ 2: Does the integration of additional gamification elements enhance the qualities of the app in terms of need satisfaction, motivation and user experience?
- RQ 3: Does the integration of additional gamification elements affect environmental attitudes and prospective waste separation behavior?

4 SYSTEM DESCRIPTION

To guide users through a proper recycling process, our mobile application has to fulfill three main goals. First, the application shall introduce users to the different waste types and their respective containers for disposal. This should lead to a better understanding of waste separation in general and reduce the amount of wrongly disposed waste. Second, the application needs to assist the correct disposal in a case-by-case situation. This should further reduce the amount of wrongly



(a) Home screen

(b) Trash with QR-codes

Fig. 1. Home screen and trash with QR-codes

disposed waste and facilitate the process in general. Third, the application needs to increase a user's motivation and present recycling in a meaningful way.

The following section describes our design decisions to develop a system fulfilling these requirements. To present the system, we first demonstrate the scope and functionality of the basic version and subsequently present the additionally gamified version with the respective adjustments.

4.1 Basic Version

4.1.1 Main structure. The application is subdivided into three distinct parts and allows navigation between these sections with a series of buttons at the top of the screen. Subsequently, we first describe the main structure of the application in this section and present additional features in section 4.1.2.

Introducing recycling principles. First, the home screen displays eight different types of trash bins based on German standards. Each includes a touchable help function, showing which waste would have to be inserted into the respective bin (see Figure 1 a). As such, the screen presents the most relevant information, which can serve as a basis for highly accurate, but most likely not perfect separation of waste (due to unintuitive requirements and exceptions), as early in the interaction as possible.

Assisting the recycling process. Second, to assist the recycling process, we decided to exploit the benefits of AR to provide a direct connection with the real waste. However, the assistance for correct waste disposal of all available products would be out of scope of this project. Hence, we decided to approach this aspect by prototypically adding markers to a selection of items as displayed in Figure 1 b. This simulates the identification of objects by scanning a code. The AR view only contains the navigation button at the top of the screen as well as the camera input of the tablet. Scanning one of the QR-codes superimposes a 3D-object of the respective waste, e.g., a 3D-model of a bottle. Upon touch, the user takes the selected object to the home screen. In this way, using AR not only provides a direct connection to the real world, but also enables the user to actively pull the waste into the application. On this home screen, the user can throw the waste into one of the eight bins via drag and drop gesture with direct feedback on correct or incorrect assignment. This ultimately allows us to evaluate the general approach of assisting the recycling process and derive recommendations if successful.

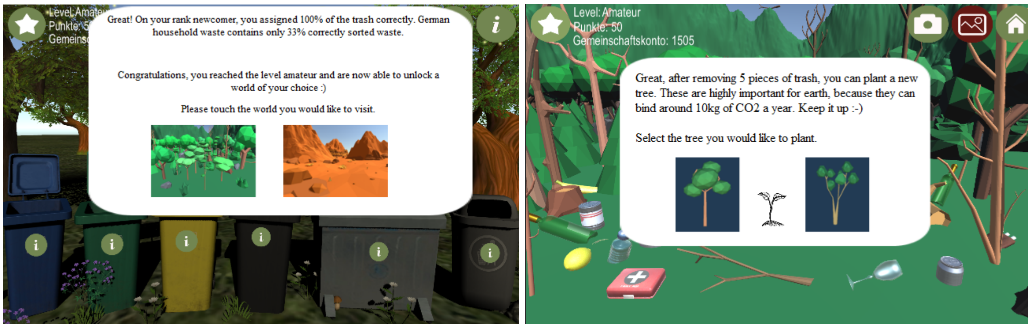
Fostering knowledge. Third, the user can access two different completely virtual environments, one modeled after a forest and one after a desert. These environments serve as the basis for additional narrative within the application, as well as for gamification elements in the enhanced version. In contrast to the first two parts of the application, the theme of recycling is addressed less on a level to convey specific information, instead this part is set up to stress the connection of recycling to environmental protection. Within these environments, the user can collect pieces of trash, which are dispersed throughout the view, which are instantly removed on touch and not transferred to the home screen. Therefore, the user can clean up these environments, which is interconnected with the subsequent additional features. This effect is enhanced further as the user is prompted to plant additional vegetation within the environment, once a sufficient amount of trash has been removed. The trash is set to reappear at randomized longer time intervals, to allow for long term interaction, which is is not reflected in the current short term user evaluation.

4.1.2 Additional features. For the basic version, the order for interaction is predetermined. When starting the application, a short introduction is shown, which supplies information about the current climate crisis, the importance of waste separation as well as a tree-planting-initiative. Users are informed, that reaching a predetermined score, a tree will be planted, further strengthening the connection between the behavior within the app with the outside world, not only in respect to recycling, but to climate change as well. After the initial short introduction, conveying the main themes of the application, the users are prompted to use the AR view to scan the trash and assign it to the recycling bins. To achieve points within the app users can make use of the virtual environments and collect trash, with one point for each piece, which is limited due to long respawn timers. However, the main approach is to scan the QR-codes attached to the real world trash (the equivalent of barcodes in an applied setting) using the AR view and subsequently correctly assign the trash to one of the bins on the home screen. Once this step is completed, the button to generate a random piece of trash is unlocked. This allows the user to gain additional points by assigning the random trash to the correct bin. A button with a star shows the different achievable levels, while the current score is displayed on its right (see Figure 1 a). Using the scanning feature or random generation, the users are able to advance their level to unlock the virtual forest and desert environments. The score is directly connected to the aforementioned levels to create a sense of potential long term goals, even though the amount is unobtainable within the predicted interaction time with the prototype. The top button bar of the user interface also includes an help option, which briefly presents the options within the respective part of the application (see Figure 1 a). This ultimately scaffolds the learning process about proper recycling.

4.2 Gamified Version

The gamified version contains all features of the basic version but has been extended with additional gamification elements. We considered the approaches of Aparicio et al. [3], Blohm and Leimeister [7], Nicholson [37], as well as Sakamoto et al. [48] during the conceptualization and design of the enhanced version, with the aim to meaningfully integrate gamification. The overarching goal for the gamified version was an additional effect on need satisfaction, especially autonomy, competence, and relatedness, as well as on motivation in general. We outline the implemented gaming elements and the changes to the basic version in the following section.

Narrative involvement. During the introduction, participants were not only informed about climate change, but were presented with the opportunity to make a valuable contribution as part of the user group, testing the application. This was realized by the presentation of a fictional community account, a collection of all points added up across all participants, which would be a basis for a donation to plant actual trees. The integration of the community account should result



(a) Level up (b) Choice in planting

Fig. 2. Level up and planting a tree after removing trash

in a real world goal for the participants, adding meaning to collected points and increasing their relevance as well as the importance to interact with the application as a whole, which according to Nicholson [37] should enhance motivation. To remind users of this mechanism, the points of the community account are presented directly under one's own points throughout the whole interaction. The inclusion of the player in a group of co-players as part of the tree donation activity aims to promote the satisfaction of social relatedness [3, 28, 44, 46]. Because the goal can be achieved collectively, sharing and competition among each other is encouraged and the ideological value is considered [7, 48]. Thus, in this version, a narrative frame was placed around the context of the application and meaning was given to the user's actions, which should have a positive effect on social relatedness [7, 41, 46]. The presentation of an approach to combat climate change in the gamified version, which is also relevant outside the app, should therefore result in an improved motivation regarding the overarching topic of environment protection [7, 26].

Feedback and points. To promote need satisfaction in regard to competence, the feedback in the gamified version is more positive and supportive in wording in contrast to the purely informative feedback in the basic version. The feedback for the user is prepared to be efficient and provides instructions for correct behavior if trash has been sorted incorrectly, allowing participants to quickly learn from mistakes, which should be perceived as helpful by the users [26, 33]. This should in turn support participants to document their own behavior and to adhere to personal goals as well as to enable a sense of accomplishment and competence [3, 7].

After each level advancement, the participants are informed about the percentage of trash, which they correctly sorted within the last level. This element serves as an individual proof of performance, reflecting one's effectiveness and enabling users to set their own goals, which should in turn address the need for competence as well as intrinsic motivation, and might even have a positive impact on attitude change [3, 33, 46]. According to Nicholson [37], it is important to create meaningful content, therefore the performance of the users are put in relation to actual statistics of correct waste separation within Germany (see Figure 2 a). The positive effects of a scoring system on the need for competence have already been demonstrated in several studies [3, 24, 28, 46]. However, to imbue the points with meaning and prevent them to be perceived simply as a number and therefore affect competence [54], they are strongly connected to the real world via the community account to plant a tree. Therefore, the personal contribution to the community account is pointed out every time when a new level is achieved, which should additionally address the need for relatedness due to the group effort [3, 44].

Choice. To address the need for autonomy, the users in the gamified version receive additional choices within the application relative to the basic version [3, 37, 44]. The order of the interaction with the app is not predetermined and the users can freely use all features of the app after the introduction. In contrast to the basic version, users can also decide on the order in which they unlock the two virtual environments. However, the options to unlock them requires the same amount of points as in the basic version. Furthermore, when cleaning either the virtual desert or forest environment, the user has a choice of two possible trees to plant, once enough trash has been removed (see Figure 2 b). These additional choices should give the user more perceived control over the application, reinforcing perceived autonomy [7].

4.3 Technology

The application was created in Unity and exported to a tablet running Android and can therefore be subsequently extended. We implemented the Vuforia Engine to integrate AR functionality. To this end, we created several unique QR-codes, which can be recognized by the software while the camera of the tablet is active and the application is running. For the current prototype we attached the QR-codes on real world trash objects and presented similar looking 3D-objects when displayed in AR.

5 USER STUDY

5.1 Participants

In total, 31 students of blinded university took part in the experiment (age: $M = 23.13$, $SD = 3.26$), with 16 self-reporting as male and 15 self-reporting as female. None indicated being of diverse gender. Participants were randomly allocated to the gamified condition ($n = 14$) and the basic condition ($n = 17$). Students received partial course credit for participation in the experiment.

5.2 Measures

We present Cronbachs alpha and the number of items for each questionnaire used within the experiment in Table 2.

To assess need satisfaction for competence, autonomy and relatedness we used the questions by Sheldon and Filak [55], which include one subscale for each construct.

Because other needs beside competence, autonomy and relatedness might be relevant, as outlined in the typology of 13 needs by Desmet and Fokkinga [15] we used subscales of an additional need satisfaction questionnaire by Wolf et al. [62] based on this typology. The subscales for competence, autonomy and relatedness were used as reliability measures and in addition, we assessed the subscales for stimulation, impact, morality, recognition and community, which we considered applicable in the context of the application.

For situational intrinsic, identified, and extrinsic motivation during interaction with the application, we used the Situational Motivation Scale questionnaire [22].

To have an established measure to represent intentions of use we assessed the respective subscale of the toolbox by Salaschek and Thielsch [49], with slight adjustments to refer to the application instead of a website.

Stoeva and Alsriksson [57] provide an 18 item questionnaire, which directly refers to several aspects regarding recycling and waste separation using six different subscales. We included five of the subscales, namely attitude, subjective norm, perceived behavioral control, intention and behavior. However, we excluded the scale referring to the satisfaction with local facilities, because unlike the original study the questionnaire was not used in a locality common for all participants and reference to the local facilities i.e. the waste separation within the university was also not applicable due to online lectures during the Covid19 pandemic.

To address environmental attitudes and beliefs, which supply a wider perspective relative to the questionnaire specifically on recycling, we also used the new ecological paradigm questionnaire [20]. The instrument was included even though it is considered to be in need for revision [31] but currently there is no established alternative.

For assessment of the user experience with the app we also included the User Experience Questionnaire [29] as an established measure. For a comparison extending on the comparison of experimental conditions we used published benchmarks of 452 products for the User Experience Questionnaire [52] for an additional perspective on user experience.

Participants were also asked to give positive as well as negative feedback for the app. Input into the respective textboxes was mandatory.

Table 2. Reliability referenced as Cronbachs alpha and number of items for each scale.

Scale	Number of items	Cronbachs alpha
Autonomy[a]	3	.79
Competence[a]	3	.68
Relatedness[a]	3	.42
Autonomy[b]	4	.87
Competence[b]	4	.81
Relatedness[b]	4	.89
Stimulation	4	.70
Impact	4	.87
Morality	4	.69
Recognition	4	.73
Community	4	.85
Intrinsic motivation	4	.74
Identified motivation	4	.66
Extrinsic motivation	4	.77
Intent to use	4	.85
Waste separation behavior	15	.75
Environmental attitudes	15	.56
User experience	26	.93

[a] Based on Sheldon and Filak , [b] Based on Wolf et al.

5.3 Procedure

Initially participants were advised about current hygiene procedures concerning Covid19. Subsequently, they were informed about content and procedure of the study and gave informed consent. Next, the participants received a tablet running the application based on their randomly allocated condition. They were informed that they had seven minutes to freely interact with the application without further instruction by the experimenter. We chose the duration based on pre-tests. As basis for interaction eleven different pieces of rubbish, each marked with an individual QR-code (see Figure 1b) were presented to the participants. Users were notified once only one minute remained to interact with the application. After the seven minutes had elapsed, participants were asked to return the tablet and fill in the measures outlined in 5.2. At the end of the experiment the participants were informed that a donation to plant trees would be conducted regardless of their performance.

6 RESULTS

All analyses were conducted using IBM SPSS Version 28. Due to the small sample size, we used Mann-Whitney U tests with alpha set at .05, for descriptive data and statistical tests see Table 3.

Table 3. Mean values for all measures across both conditions, SDs in parentheses. U & p represent results of Mann-Whitney U tests.

Scale	Range	Gamified condition	Basic condition	U	p
Autonomy[a]	1-5	3.82 (1.01)	3.38 (0.71)	81.50	.133
Competence[a]	1-5	3.41 (0.94)	3.38 (0.58)	113.50	.825
Relatedness[a]	1-5	3.49 (0.73)	3.24 (0.67)	95.00	.333
Autonomy[b]	1-7	5.00 (1.35)	4.30 (1.07)	80.00	.120
Competence[b]	1-7	4.84 (0.87)	4.82 (1.21)	111.00	.750
Relatedness[b]	1-7	2.63 (1.13)	3.20 (1.20)	83.00	.151
Stimulation	1-7	4.84 (0.86)	4.98 (0.89)	108.50	.675
Impact	1-7	4.87 (0.78)	4.86 (1.30)	108.00	.661
Morality	1-7	5.16 (0.72)	5.40 (1.19)	86.00	.188
Recognition	1-7	4.38 (1.06)	4.79 (0.93)	85.00	.175
Community	1-7	3.66 (1.18)	4.20 (1.26)	95.00	.338
Intrinsic motivation	1-7	4.90 (0.95)	4.71 (1.03)	111.00	.750
Identified motivation	1-7	4.96 (0.90)	4.66 (0.97)	96.50	.369
Extrinsic motivation	1-7	3.53 (1.54)	3.89 (1.11)	108.00	.660
Intentions of use	1-7	4.60 (1.19)	4.59 (1.06)	123.00	.873
Waste separation behavior	1-5	4.46 (0.29)	4.41 (0.34)	123.00	.873
Environmental attitudes	1-5	3.74 (0.27)	3.70 (0.38)	114.50	.858
User experience	1-7	5.37 (0.73)	5.54 (0.63)	103.50	.538

[a] Based on Sheldon and Filak , [b] Based on Wolf et al.

6.1 Comparison User Experience benchmark

Relative to the Benchmark by Schrepp et al. [52] and their proposed categories for the comparison, both versions of the application are either rated as "above average" or "good" for all subscales of the questionnaire, with the exception of one case with "below average". In this context "above average" is defined as 25% of the results in the benchmark are better than the evaluated product, 50% of the results are worse. "Good" indicates that 10% of the results in the benchmark are better than the evaluated product, 75% of the results are worse. While "below average" was set as 50% of the results in the benchmark are better than the evaluated product, 25% of the results are worse. The comparison is presented in Table 4.

6.2 Qualitative Data

Positive feedback. The positive comments in both conditions were very diverse. We therefore aggregated their content and incorporated these in Table 5. The qualitative feedback of one participant could be assigned to multiple categories if different aspects were mentioned within the text. Aspects, which were only mentioned once and could not be adequately integrated into the categories were omitted.

Negative feedback. The negative comments for both conditions were highly homogeneous. For both versions, most participants noted problems with using a drag and drop action to assign a piece

Table 4. Mean values of UEQ subscales in both conditions, SDs in parentheses. Based on scale of 1-7. Assessment of category based on Schrepp et al. (2017)

Subscale	Gamified condition	Basic condition
Attractiveness	5.42 (0.96) - above average	5.67 (0.61) - good
Perspicuity	5.64 (1.06) - above average	5.55 (1.03) - above average
Stimulation	5.44 (0.80) - good	5.55 (1.02) - good
Efficiency	5.21 (0.85) - above average	5.32 (0.74) - above average
Novelty	5.49 (0.79) - good	5.50 (1.20) - good
Dependability	4.99 (0.89) - below average	5.55 (0.37) - good

Table 5. Count of aggregated positive comments on both versions of the application.

Condition	Content	n
Basic condition	Intuitive and easy to use	5
	Clear and creative layout	4
	High learning support by supplying correct solution	4
	Additional information for waste separation and climate change	4
	Reward system including points and unlockable worlds	3
	Gamified approach	2
Gamified condition	Meaningful application	5
	Clear and creative layout	4
	Intuitive and easy to use	4
	Fun to interact with the application	4
	Direct and positive feedback	4
	Highly suitable application for children	3
	High learning support by supplying correct solution	3
	Reward system including points and unlockable worlds	2

of trash to one of the bins ($n_{\text{basic condition}} = 12$, $n_{\text{gamified condition}} = 12$). In both conditions it was noted twice, that the bins for different kinds of glass waste were too close together. For the gamified version, it was also mentioned twice, that the order of interaction was not always clear. As with the positive feedback, comments which only occurred once were omitted.

7 DISCUSSION

The evaluation of our prototype found no significant difference with respect to the need satisfaction, motivation, and user experience between the basic and the gamified version. The lack of a difference between the two tested versions is explainable in two ways.

On the one hand, the differences between the two versions were rather small and hence might have been not prominent enough to cause a significant difference. In addition, because waste separation and environmental protection are important topics by themselves, participants might have already been highly motivated to discover new ways to learn about and deal with recycling. Knowledge about waste separation is also high in general within the target user group.

On the other hand, the participants interacted with the application for only seven minutes during our experiment, which might have been insufficient to cause a more pronounced difference. Because the integration of gamification is especially effective to create an incentive for longer use, our gamified version might only result in noticeable effects if it is used over a longer period of time.

The general novelty of the application concept might have also influence the perception of the app more strongly than the gamification manipulation itself. Based on our results, we cannot draw conclusions with respect to the influence of gamification on the perception of the application or the stance towards recycling in general. Therefore, our research questions two and three, which aim to investigate additional benefits of the gamified version are not supported within the present study.

For a future version of the application, the integration of gamification would have to be more prominent. In addition, a long-term study of our application to investigate the effects of gamification in more detail, would be necessary. Such a long-term study would allow for an investigation of the novelty effect and whether participants remain motivated to use the application continuously.

Despite this statistical lack of an influence of gamification, the user study indicated a high acceptance of the application in general. The intentions of use, waste separation behavior, and user experience were at an upper medium or high level in both conditions. This shows that the provided learning environment and assistance to identify the waste type of different products was well perceived. Our first research question on an overall acceptance of this approach to use a mobile application to support waste separation can therefore be considered as being supported.

The results also indicate some areas of potential improvement for the next iteration of the application. Based on the questionnaire results in combination with the qualitative data, it appears that the participants would prefer the more guided approach of the basic version, as indicated by the better assessment regarding dependability, as well the comments on ambiguous order for interaction. For the assignment of trash to one of the bins, the qualitative comments clearly indicated that a readjustment of the interaction is necessary. Overall, this result is promising as it provides first indications of the effectiveness of mobile applications for the assistance of recycling. Future work can extend the current approach of scanning products and use real barcodes instead of image targets. This would allow for an in-depth investigation whether an AR recycling assistance application could be used effectively in daily living, e.g., at home.

8 IMPLICATIONS

Our research indicates that mobile devices provide an easy way to guide users to recycle properly, to inform them about waste types, and to assist in case-by-case recycling decisions. In this way, the design of our prototype successfully demonstrated how mobile technology integrating AR can be used to facilitate recycling. This allows us to derive two central design recommendations: (1) Operating the application should always be clear, encouraging app developers to pay particular attention providing a comprehensible interaction flow; (2) Participants in both conditions highlighted the intuitive user interface, thus our app might serve as an exemplary approach for an application in this field integrating a design concept that similar applications might take into account.

This app concept can further be combined with a database storing barcodes and recycling information of frequently bought and difficult to recycle products in grocery stores, users can be guided to proper recycling. In addition, such an approach is ideal to quickly learn about recycling procedures in Germany, but could be adapted to fit other countries and their respective waste separation system. As a first step, we plan an adaption of the app for primary students learning waste separation and a subsequent evaluation. Furthermore, a scenario in which the app is used in an applied setting for a longer period of time would be highly desirable, because we could not only investigate knowledge gain, but also behavior change. For this approach, the app could ideally not only make use of the barcodes of products, but use the advances in machine learning to identify trash [36]. However, as indicated by Liu et al. [30], this is currently not implementable for rubbish without predetermined shape.

9 LIMITATIONS

Only a small number of university students participated in our study. This creates two potential limitations of our findings. First, the small sample size must be taken into account when evaluating and classifying the results. Second, recycling is an issue that concerns everyone and to which everyone should contribute. Hence, our results only provide a limited view into the general acceptance of such a mobile AR application. The currently used QR codes should be replaced with barcodes on real products, for a more life-like use of the app. Future work should aim for a more heterogeneous group of participants, including people from different age groups and population strata. This should also include groups with initially lower motivation and/or knowledge concerning waste separation.

10 CONCLUSION

To improve and assist recycling, mobile devices are ideal as they can provide an easy access to knowledge and recommendations. This paper presented a mobile application guiding users through proper recycling processes, teaching them to correctly identify waste types, and assisting them with the identification of potentially unknown products. We integrated AR elements due to their motivational benefits and the strong link created between knowledge within the application and the real world. Because gamification can induce higher motivation to use an application for a longer period of time, we also designed a gamified version.

In a comparative user study, we found generally high acceptance and positive user experience of the mobile application. However, the additional effects of gamification were limited, resulting in no significant improvement relative to the basic version of the application. This result is important as it reveals an already high level of motivation to recycle and the high value of assistance to reduce uncertainties with respect to waste separation.

Future research shall investigate the long-term effects of using a gamified recycling app. Another future research direction is the extension of the recycling assistant. Instead of using image targets, it should recognize products by their barcode or mere shape and recommend the correct approach to recycling.

REFERENCES

[1] Jenilyn L. Agapito and Ma. Mercedes T. Rodrigo. 2018. Investigating the Impact of a Meaningful Gamification-Based Intervention on Novice Programmers' Achievement *(Artificial Intelligence in Education)*. Springer International Publishing, 3–16.

[2] Lidia Aguiar-Castillo, Julio Rufo Torres, Petra De Saa Pérez, and Rafael Pérez Jiménez. 2018. How to encourage recycling behaviour? The case of WasteApp: a gamified mobile application. *Sustainability (Switzerland)* (2018).

[3] Andrés Francisco Aparicio, Francisco Luis Gutiérrez Vela, José Luis González Sánchez, and José Luis Isla Montes. 2012. Analysis and Application of Gamification. In *Proceedings of the 13th International Conference on Interacción Persona-Ordenador* (Elche, Spain) *(INTERACCION '12)*. Association for Computing Machinery, New York, NY, USA, Article 17, 2 pages. https://doi.org/10.1145/2379636.2379653

[4] Ronald T. Azuma. 1997. A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environments* 6, 4 (1997), 355–385.

[5] Jorge Bacca, Silvia Baldiris, Ramon Fabregat, Sabine Graf, and Kinshuk. 2014. Augmented Reality Trends in Education: A Systematic Review of Research and Applications. *Educational Technology & Society* 17, 4 (2014), 133–149.

[6] Gabriel Barata, Sandra Gama, Joaquim Jorge, and Daniel Gonçalves. 2013. Improving participation and learning with gamification. In *Proceedings of the First International Conference on Gameful Design, Research, and Applications - Gamification '13*, Lennart E. Nacke, Kevin Harrigan, and Neil Randall (Eds.). ACM Press, New York, New York, USA, 10–17.

[7] Ivo Blohm and Jan Marco Leimeister. 2013. Gamification. *Business & information systems engineering* 5, 4 (2013), 275–278.

[8] Pedro Centieiro, Teresa Romão, and A Eduardo Dias. 2011. A location-based multiplayer mobile game to encourage pro-environmental behaviours. In *Proceedings of the 8th International Conference on Advances in Computer Entertainment Technology*. 1–8.

[9] Jen-Wei Chang and Hung-Yu Wei. 2016. Exploring the Possibility of Using Humanoid Robots as Instructional Tools for Teaching a Second Language in Primary School. *Educational Technology & Society* 19, 2 (2016), 177–203.

[10] Kin Meng Cheng, Ah Choo Koo, Junita Shariza Mohd Nasir, and Shen Yuong Wong. 2021. Playing Edcraft at Home: Gamified Online Learning for Recycling Intention during Lockdown. *F1000Research* 10 (2021).

[11] Edward L Deci and Richard M Ryan. 2008. Facilitating optimal motivation and psychological well-being across life's domains. *Canadian Psychology/Psychologie Canadienne* 49, 1 (2008), 14.

[12] Edward L Deci and Richard M Ryan. 2011. *Self-determination theory.* Sage Publications, Inc., 416–437.

[13] Edward L. Deci, Allan J. Schwartz, Louise Sheinman, and Richard M. Ryan. 1981. An instrument to assess adults' orientations toward control versus autonomy with children: Reflections on intrinsic motivation and perceived competence. *Journal of Educational Psychology* 73, 5 (1981), 642–650. https://doi.org/10.1037/0022-0663.73.5.642

[14] Hojjat Dehghanzadeh, Hashem Fardanesh, Javad Hatami, Ebrahim Talaee, and Omid Noroozi. 2019. Using gamification to support learning English as a second language: a systematic review. *Computer Assisted Language Learning* (2019), 1–24.

[15] Pieter Desmet and Steven Fokkinga. 2020. Beyond Maslow's pyramid: introducing a typology of thirteen fundamental needs for human-centered design. *Multimodal Technologies and Interaction* 4, 3 (2020), 38.

[16] Sebastian Deterding, Dan Dixon, Rilla Khaled, and Lennart Nacke. 2011. From game design elements to gamefulness: Defining Gamification. In *Proceedings of the 15th International Academic MindTrek Conference on Envisioning Future Media Environments - MindTrek '11*, Artur Lugmayr, Heljä Franssila, Christian Safran, and Imed Hammouda (Eds.). ACM Press, New York, New York, USA, 9–15.

[17] Christo Dichev, Darina Dicheva, Galia Angelova, and Gennady Agre. 2015. From Gamification to Gameful Design and Gameful Experience in Learning. *Cybernetics and Information Technologies* 14, 4 (2015), 80–100.

[18] Darina Dicheva, Christo Dichev, Gennady Agre, and Galia Angelova. 2015. Gamification in Education: A Systematic Mapping Study. *Educational Technology & Society* 18 (2015), 75–88.

[19] Athanasios Drigas and Pantelis Angelidakis. 2017. Mobile Applications within Education: An Overview of Application Paradigms in Specific Categories. *International Journal of Interactive Mobile Technologies (iJIM)* 11, 4 (2017), 17.

[20] Riley E Dunlap and Kent D Van Liere. 1978. The "new environmental paradigm". *The journal of environmental education* 9, 4 (1978), 10–19.

[21] Denisa Gibovic and Andrea Bikfalvi. 2021. Incentives for Plastic Recycling: How to Engage Citizens in Active Collection. Empirical Evidence from Spain. *Recycling* 6, 2 (2021), 29.

[22] Frédéric Guay, Robert J Vallerand, and Céline Blanchard. 2000. On the assessment of situational intrinsic and extrinsic motivation: The Situational Motivation Scale (SIMS). *Motivation and emotion* 24, 3 (2000), 175–213.

[23] L. Hakulinen, T. Auvinen, and A. Korhonen. 2013. Empirical Study on the Effect of Achievement Badges in TRAKLA2 Online Learning Environment. In *2013 Learning and Teaching in Computing and Engineering*. IEEE, 47–54.

[24] Juho Hamari, J. Koivisto, and H. Sarsa. 2014. Does Gamification Work? – A Literature Review of Empirical Studies on Gamification. In *2014 47th Hawaii International Conference on System Sciences*. 3025–3034. https://doi.org/10.1109/HICSS.2014.377

[25] B. Haßler, L. Major, and S. Hennessy. 2016. Tablet use in schools: a critical review of the evidence for learning outcomes. *Journal of Computer Assisted Learning* 32, 2 (2016), 139–156.

[26] Miralem Helmefalk and Joacim Rosenlund. 2020. Make Waste Fun Again! A Gamification Approach to Recycling. In *Interactivity, Game Creation, Design, Learning, and Innovation*, Anthony Brooks and Eva Irene Brooks (Eds.). Springer International Publishing, Cham, 415–426.

[27] Jincheul Jang, Jason J. Y. Park, and Mun Y. Yi. 2015. Gamification of Online Learning. In *Artificial Intelligence in Education*, Cristina Conati, Neil Heffernan, Antonija Mitrovic, and M. Felisa Verdejo (Eds.). Lecture notes in computer science Lecture notes in artificial intelligence, Vol. 9112. Springer, Cham, 646–649.

[28] Jonna Koivisto and Juho Hamari. 2019. The rise of motivational information systems: A review of gamification research. *International Journal of Information Management* 45 (2019), 191–210.

[29] Bettina Laugwitz, Theo Held, and Martin Schrepp. 2008. Construction and evaluation of a user experience questionnaire. In *Symposium of the Austrian HCI and usability engineering group*. Springer, 63–76.

[30] Sijiang Liu, Bo Jiang, and Jie Zhan. 2017. Deep learning application: rubbish classification with aid of an android device. In *Second International Workshop on Pattern Recognition*, Vol. 10443. SPIE.

[31] Carina Lundmark. 2007. The new ecological paradigm revisited: anchoring the NEP scale in environmental ethics. *Environmental education research* 13, 3 (2007), 329–347.

[32] Elisa D. Mekler, Florian Brühlmann, Alexandre N. Tuch, and Klaus Opwis. 2017. Towards understanding the effects of individual gamification elements on intrinsic motivation and performance. *Computers in Human Behavior* 71 (2017), 525–534.

[33] Cees Midden, Teddy McCalley, Jaap Ham, and Ruud Zaalberg. 2008. Using persuasive technology to encourage sustainable behavior. *Sustainability WS Pervasive* 113 (2008), 83–86.

[34] Ann Morrison, Antti Oulasvirta, Peter Peltonen, Saija Lemmela, Giulio Jacucci, Gerhard Reitmayr, Jaana Näsänen, and Antti Juustila. 2009. Like bees around the hive. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (ACM Conferences)*, Dan R. Olsen (Ed.). ACM, New York, NY, 1889–1898. https://doi.org/10.1145/1518701.1518991

[35] Lennart E. Nacke and Sebastian Deterding. 2017. The maturing of gamification research. *Computers in Human Behavior* 71 (2017), 450–454.

[36] Du Ni, Zhi Xiao, and Ming K. Lim. 2021. Machine learning in recycling business: an investigation of its practicality, benefits and future trends. *Soft Computing* 25, 12 (2021), 7907–7927. https://doi.org/10.1007/s00500-021-05579-7

[37] Scott Nicholson. 2012. A User-Centered Theoretical Framework for Meaningful Gamification. In *Games+Learning+Society 8.0*.

[38] Florian Niebling and Marc Erich Latoschik. 2018. Browsing Spatial Photography using Augmented Models. In *Proceedings of the 17th IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, ACM, 47–48.

[39] Iulian Radu. 2014. Augmented reality in education: a meta-review and cross-media analysis. *Personal and Ubiquitous Computing* 18, 6 (2014), 1533–1543.

[40] Dicky Rawendy, Yi Ying, Yulyani Arifin, and Kelly Rosalin. 2017. Design and Development Game Chinese Language Learning with Gamification and Using Mnemonic Method. *Procedia Computer Science* 116 (2017), 61–67.

[41] Byron Reeves and J Leighton Read. 2009. *Total engagement: How games and virtual worlds are changing the way people work and businesses compete*. Harvard Business Press.

[42] Jonathan P. Rossing, Willie M. Miller, Amanda K. Cecil, and Suzan E. Stamper. 2012. iLearning: The future of higher education? Student perceptions on learning with mobile tablets. 12, 2 (2012), 1–26.

[43] Jonathan P Rowe, Lucy R Shores, Bradford W Mott, and James C Lester. 2011. Integrating learning, problem solving, and engagement in narrative-centered learning environments. *International Journal of Artificial Intelligence in Education* 21, 1-2 (2011), 115–133.

[44] Richard M Ryan and Edward Deci. 2000. Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. *Contemporary Educational Psychology* (2000), 54–67.

[45] Michael Sailer, Jan Hense, Heinz Mandl, and Markus Klevers. 2013. Psychological Perspectives on Motivation through Gamification. *Interaction Design and Architecture(s) Journal* 19 (2013), 28–37.

[46] Michael Sailer, Jan Ulrich Hense, Sarah Katharina Mayr, and Heinz Mandl. 2017. How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction. *Computers in Human Behavior* 69 (2017), 371–380. https://doi.org/10.1016/j.chb.2016.12.033

[47] Michael Sailer and Lisa Homner. 2019. The Gamification of Learning: a Meta-analysis. *Educational Psychology Review* 32, 1 (2019), 77–112. https://doi.org/10.1007/s10648-019-09498-w

[48] Mizuki Sakamoto, Tatsuo Nakajima, and Todorka Alexandrova. 2012. Value-based design for gamifying daily activities. In *International Conference on Entertainment Computing*. Springer, 421–424.

[49] Martin Salaschek and Meinald T Thielsch. 2017. Toolbox zur kontinuierlichen Website-Evaluation & Qualitätssicherung. *Mensch und Computer 2017-Usability Professionals* (2017).

[50] Marc Santos, Angie Chen, Takafumi Taketomi, Goshiro Yamamoto, Jun Miyazaki, and Hirokazu Kato. 2014. Augmented Reality Learning Experiences – Survey of Prototype Design & Evaluation. *IEEE Transactions on Learning Technologies* 7, 1 (2014), 38–56.

[51] Philipp Schaper, Anna Riedmann, and Birgit Lugrin. 2021. Internalisation of Situational Motivation in an E-Learning Scenario using Gamification. In *Artificial Intelligence in Education 2021*. Springer International Publishing.

[52] Martin Schrepp, Andreas Hinderks, and Jörg Thomaschewski. 2017. Construction of a Benchmark for the User Experience Questionnaire (UEQ). *Int. J. Interact. Multim. Artif. Intell.* 4, 4 (2017), 40–44.

[53] Odile Schwarz-Herion, Abdelnaser Omran, and Hans Peter Rapp. 2008. A case study on successful municipal solid waste management in industrialized countries by the example of Karlsruhe city, Germany. *J Engineering Annals of Faculty of Engineering Hunedoara* 5 (2008), 266–273.

[54] Katie Seaborn and Deborah I. Fels. 2015. Gamification in theory and action: A survey. *International Journal of Human-Computer Studies* 74 (2015), 14–31.

[55] Kennon M Sheldon and Vincent Filak. 2008. Manipulating autonomy, competence, and relatedness support in a game-learning context: New evidence that all three needs matter. *British Journal of Social Psychology* 47, 2 (2008), 267–283.

[56] Sophia C. Steinhaeusser, Anna Riedmann, Max Haller, Sebastian Oberdorfer, Kristina Bucher, and Marc Erich Latoschik. 2019. Fancy Fruits - An Augmented Reality Application for Special Needs Education. In *2019 11th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games)*. IEEE, 1–4. https://doi.org/10.1109/VS-Games.2019.8864547

[57] Katya Stoeva and Stina Alriksson. 2017. Influence of recycling programmes on waste separation behaviour. *Waste Management* 68 (2017), 732–741.

[58] C-H. Su and C-H. Cheng. 2015. A mobile gamification learning system for improving the learning motivation and achievements. *Journal of Computer Assisted Learning* 31, 3 (2015), 268–286.

[59] Alexander Tillmann and Claudia Bremer. 2017. Einsatz von Tablets in Grundschulen. In *Tablets in Schule und Unterricht*, Jasmin Bastian and Stefan Aufenanger (Eds.). Springer Fachmedien Wiesbaden, Wiesbaden, 241–276.

[60] Jörg Wagner, Marko Günther, Hans-Bernhard Rhein, and Peter Meyer. 2018. *Analyse der Effizienz und Vorschläge zur Optimierung von Sammelsystemen (Hol- und Bringsysteme) der haushaltsnahen Erfassung von Leichtverpackungen und stoffgleichen Nichtverpackungen auf der Grundlage vorhandener Daten.*

[61] Catherine Walter-Laager, Kathrin Brandenberg, Luzia Tinguely, Jürg Schwarz, Manfred R. Pfiffner, and Barbara Moschner. 2017. Media-assisted language learning for young children: Effects of a word-learning app on the vocabulary acquisition of two-year-olds. *British Journal of Educational Technology* 48, 4 (2017), 1062–1072.

[62] Sara Wolf, Franzisca Maas, Pauline Künzl, Anna Hohm, and Jörn Hurtienne. 2022. UNeedS: Development of Scales to Measure the Satisfaction and Frustration of 13 Fundamental Needs. In *Mensch und Computer 2022*. https://doi.org/10.1145/3543758.3547572

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