Does Physicality Enhance the Meaningfulness of Gamification? Transforming Gamification Elements to their Physical Counterparts

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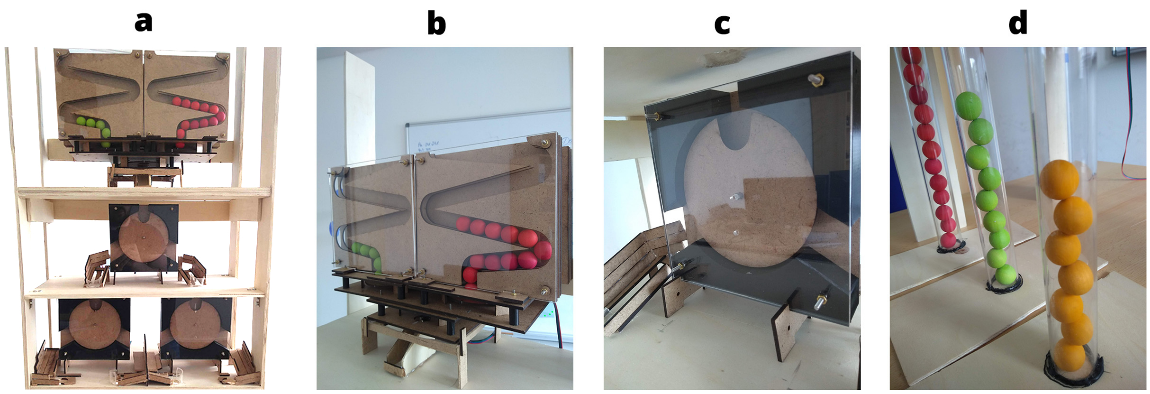

Fig. 1. Physical gamification prototype for the gamification elements points and leaderboard. a) shows an overview of the prototype, b) shows the marble magazines, c) shows the splitters to distribute marbles to the d) output tubes

Gamification has been shown to successfully help users in reaching their goals, and enhancing their user experience. However, it has also been criticized for adding arbitrary rewards to non-game activities, which is often perceived as being meaningless. To counter this, we investigate whether physical gamification, i.e. transforming virtual gamification elements (such as points or leaderboards) to their physical counterparts, is perceived as more meaningful by users. Based on an elicitation lab-study (N=12), we contribute concrete transformations from virtual to physical gamification elements and derive design recommendations for physical gamification systems. Next, we use these recommendations to implement a prototype for the gamification elements points and leaderboard. In a subsequent lab experiment, we investigate the perception of physical gamification elements and compare our prototype to its virtual counterpart (N=12). Our results show that physical gamification elements are perceived as significantly more persuasive and more meaningful than their virtual counterparts.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**.

Additional Key Words and Phrases: gamification, physicality, virtuality, meaningfulness

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1 INTRODUCTION

Gamification, *the use of game design elements in non-game contexts* [6], has been used in various domains including education, health, crowdsourcing, and commerce [13]. It has become its own research field within Human Computer Interaction (HCI) and has successfully made the leap into industry [29]. While most studies investigating the effects of gamification have reported positive results [40], there also remains significant criticism. One such common critique is that gamification typically adds a scoring system to a non-game activity, thus utilizing the least interesting part of a game [30]. This mere addition of external rewards to an activity, which is not rewarding in itself, has lead to terms such as *pointsification* [30], *exploitationware* [3], *sugar-coating* or *chocolate-dipped broccoli* [7] to describe gamification or gamification-related concepts. At its heart, these negatively charged synonyms can be related back to a lack of personal relevance caused by the notion that the purely virtual gamification elements such as points, badges or leaderboards, are often *meaningless* to the user [30, 45].

The psychological condition of meaningfulness is considered an important psychological state, which individuals strive to reach when engaging in activities [24]. Meaningfulness is defined as the value of an activity, judged in relation to an individual's ideals [24]. A low perceived meaningfulness of an activity ultimately leads to feelings of alienation or disengagement [24], potentially explaining the aforementioned issues with gamification. Moreover, meaning has been proposed as an own basic psychological need [39], besides autonomy, relatedness and competence, in Self-Determination Theory, a theory on human motivation [37, 39]. Thus, enhanced meaningfulness might be beneficial for users' motivation, which is often aimed to be increased when using gamification. In response, research has been conducted to better understand how gamification elements can be made more meaningful to users. Nicholson [30] pointed out the importance of providing relevant information to users, allowing them to customize a gameful system and increasing its transparency. The positive effects of such customizable gamification setups was shown by Lessel et al. [20, 22]. However, there seem to be more factors having an influence on the meaningfulness of gamification.

One factor addressing meaningfulness concerns the *virtuality* of gamification, i.e. , the fact that almost all gamification interventions made use of virtual game elements [13, 40], although Deterding et al. [6] explicitly stated in their definition that gamification is not limited to digital applications or services. In fact, users of gameful applications reported missing value in virtual rewards due to a lack of practical relevance [12]. This is supported by studies comparing tangible and intangible rewards. Tangible rewards were shown to increase the user activity substantially more than intangible rewards [27] and to be advantageous over intangible rewards in motivating users over a long time-span [11]. Additionally, outside of the gamification domain, it has been shown that physicality leads to increased enjoyment, playfulness and realism [50]. In line with these findings, participants of a recent study on gameful fitness applications by Ha et al. [12] demanded for physical rewards, instead of purely relying on virtual ones. However, to the best of our knowledge, the transformation of virtual gamification elements such as points or leaderboards, into physical counterparts has not been investigated yet. Furthermore, evaluating whether such physical gamification elements are more meaningful to users due to their *existence in the real, physical world*, remains an unaddressed opportunity.

Our work aims to bridge the gap in understanding of the relationship between physicality and meaningfulness for gamification research. This is done by investigating how virtual gamification elements can be mapped to their physical counterparts and whether physical gamification elements are perceived as more meaningful and engaging within the context of encouraging physical activities. To this purpose, we investigate the following main research questions:

RQ1: How can gamification elements–such as points, badges or leaderboards–be transformed to the physical space?

RQ2: Does physicality enhance the perceived meaningfulness of gamification elements?

To address **RQ1**, we report on the findings of an elicitation study (N=12), in which the participants elaborated on their ideas on how to mimic common gamification elements using physical objects. Based on a qualitative content analysis [15] of participants' responses, we contribute concrete transformations of gamification elements to the physical world. Building upon the results of this elicitation study, we realized a physical prototype for the gamification elements points and leaderboard (see Figure 1) and evaluated its perception in a laboratory study with 12 participants. Our findings show the feasibility of transforming virtual gamification elements to their physical counterparts, that physical gamification elements are perceived as more persuasive, and that they are considered more meaningful. These insights addressing **RQ2** provide great potential for future research on physical gamification systems.

2 RELATED WORK

To frame our contribution, we present related work in the fields of meaningful gamification, outline the relevance of physicality within gameful systems, and conclude the related work section by presenting relevant results in the field of physical and virtual interaction.

2.1 Meaningful Gamification

Nicholson [30] states that gamification should support users to form meaningful connections between gamification elements and their own goals. A core aspect to increase personal relevance and thus meaningfulness, according to Nicholson, is putting the user at the center of gameful systems. This means that users should be involved in the design process of gameful systems and that such systems should provide relevant information to the users' interests by allowing them to customize the system as they see fit. The latter has been investigated extensively by Lessel et al. [20–22]. The authors investigated the perception of allowing users to adjust gamification elements of a gamified system at runtime. They found that this approach was well-perceived and led to increased task performance [21], even if only a very limited amount of options for customization is offered [22].

Additionally, past research found that gamification – and particularly social competition – can lead to undesired behaviours [43]. For instance, users described gamification as an "electronic whip" [1] in the work context and reported feelings related to peer pressure caused by the fear of not being able to keep up with others.

Another important aspect assumed to have an impact on the meaningfulness and thus effectiveness of gameful systems, is the personal relevance of the context in which gamification is used, i.e. the effectiveness of gamification may be different across different contexts [13]. Similarly, personal relevance has been attributed as a major facet for gameful systems. This is supported by the fact that there exist various user- and player typologies such as the Hexad user type model [44], showing that the perception of gamification elements differs substantially across users [33, 44].

However, a core idea of gameful systems has not received much attention in gamification research, namely the fact that gamification elements are virtually represented. Recent research shows that virtuality may decrease the relevance of rewards in gameful settings [12]. Using virtual rewards to increase the activity of users, the authors analyzed the lived experiences with gamified mobile applications and found there is a need for more practical and meaningful virtual rewards. In this work, we contribute to the notion of whether physical representations of gamification elements could enhance the meaningfulness of gamification.

2.2 Physicality in Gameful Systems

Meder et al. [27] report findings from a large-scale study comparing tangible (i.e. physical prizes) against non-tangible (i.e. virtual) rewards. They found that tangible rewards increase the activity of users considerably more than intangible rewards.

Eickhoff et al. [10] show that physical objects are valuable for users and can create attachment in a gameful setting. The authors explored destructive games, i.e. games that use the destruction of physical objects to enhance emotional attachment. They built three prototypical two-player games, all based on the main idea that a laser cutter is used to destroy physical objects of the losing opponent. The authors found that the destruction of physical objects leads to increased excitement and emotional reactions, adding value and meaning to the game.

Lee et al. [19] developed DenTeach, a system that helps children forming healthy tooth brushing habits, by using a physical avatar that changes the color of its teeth (using RGB LEDs) when children were tooth-brushing. A smart toothbrush measured the amount of time the user had been brushing their teeth, and also detected which area of the mouth was being brushed. The authors found that their physical avatar increased the average tooth brushing time and positively impacted the attitude towards tooth-brushing. In general, the paper suggest that physical gameful systems are perceived well and can create attachment.

Similar to the work by Lee et al., Hong et al. [14] present a flower-shaped avatar that could mimic the users' sitting position, thus encouraging them to improve their posture. The authors state that virtual notifications often tend to be ignored and demonstrate that a physical system is advantageous in this regard, thus supporting the idea that physicality may enhance the relevance of feedback in general. Also, Novak and Loy [31] suggested the use of 3D printers to create physical avatars reflecting user behaviour within gamified systems encouraging physical activity. While this approach has not been investigated empirically, the authors assume that physicality might allow people attaching stories to their rewards, which supports our assumption that physicality might lead to more meaningful gamification.

Also, Dodero et al. [8] investigated gamification in a school-setting. They decided to use paper-based materials to build prototypes motivating students to overcome personal, school-related challenges. The results of two user studies show that the students had been eager to obtain rewards, such as badges, and use them to update their status on the physical progression maps. The findings show that traditionally virtual gamification elements can be translated into a physical setting, with tangible rewards visualizing progression towards predefined goals.

Khot et al. [18] designed a system called SweatAtoms that transforms the physical activity data based on heart rate into 3D printed material artifacts. They found that the material artifacts made participants more conscious about their involvement in physical activity and illustrated different levels of engagement with the artifacts.

Lastly, Degraen et al. [5] investigated physical gamification by creating a Japanese Garden consisting of interactive garden elements such as a sand basin, a waterfall, and a water pond reflecting the gamification elements of points and progress. In an online study, they investigate the perception and persuasiveness of the prototypes by using pre-recorded videos being shown to participants. They found that the prototypes were not able to keep up with a digital counterpart regarding the perceived persuasiveness. However, participants appreciated the prototypes' aesthetic design and on their relaxing nature.

While the aforementioned papers highlight the benefits of physicality in gameful systems, the systematic process of transforming virtual gamification elements to physical counterparts and a comparison of both physical and virtual gamification elements was not their focus. Also, in contrast to previous research, we investigate physical gamification more holistically by considering a broad range of commonly-used gamification elements.

2.3 Physicality in Interactive Systems

The design idea of the *marble answering machine*, envisioned by Durrel Bishop in 1992 at the Royal College of Art, is seen as one of the first tangible user interfaces and is a welcome example to demonstrate tangible interfaces in first year lectures in HCI [34, 35]. In this concept, physical marbles would represent new messages recorded with the answering machine. Placing them into a dedicated compartment would play the message. Ihsii and Ullmer later generalized this coupling of physical world and digital space as *Tangible User Interfaces* [16]. A substantial amount of research on using physical objects as proxies for interaction or to provide haptic feedback to the users followed. In the following, we will present a small subset to emphasize the positive effects created by the physical representations of virtual entities such as enjoyment, performance, or playfulness.

For instance, Xie et al. [48] compared three different versions of jigsaw puzzles that differed in their interface styles: physical (traditional), graphical and tangible in terms of enjoyment, performance and engagement. They found that participants were significantly more efficient and engaged when using interfaces that utilize physical interaction and physical objects.

Similarly, Zuckerman et al. [50] examined the benefits of a tangible user interface compared to a graphical one. They conducted a user study with 58 students in the context of an interactive application simulating water flow. The study revealed that reliability, efficiency, and portability were strong points of the graphical user interface, while the tangible user interface showed clear benefits on the user experience. It excelled in enjoyment, playfulness, physical stimulation, and perceived realism of the interaction. This is also reflected in the usability ratings of participants, revealing a clear preference for tangible user interfaces.

Taher et al. [42] explored an interactive physical representation of bar charts. They constructed a 10x10 physical bar chart and investigated different interaction methods to filter, annotate or navigate through datasets. While they did not compare their different methods to the classical spreadsheet-on-a-screen approach, they found that the interaction with their system was perceived as intuitive, informative, and enjoyable.

Zenner and Krüger [49] presented Shifty, a weight-shifting proxy device for virtual reality applications. In line with Zuckerman et al. [50], they showed that the dynamically adapted physical properties of Shifty significantly improve the users' fun and perceived realism of the interaction. These examples illustrate the benefits of physical objects in enhancing the user experience in interactive systems.

2.4 Summary

Research showed that gamification was partially perceived as meaningless, personally irrelevant and led to undesired behaviors. To address these problems, gamification research primarily investigated customization and personalization approaches. In contrast, we aim to investigate the concept of transforming virtual gamification elements into physical gamification elements. Although some research exists utilizing concepts known from games or gamification in a physical prototype, these papers were not focused on a systematic process of transforming virtual gamification elements to physical counterparts, did not compare physical against virtual gamification elements and were not aiming at an increased meaningfulness of gamification. The whole concept of using physical gamification elements to enhance the

Fig. 2. An overview of the materials given to participants

meaningfulness and personal relevance of gamification systems is motivated by previous works in other domains, showing that physicality enhances the enjoyment within interactive systems, is perceived as more valuable and in general leads to an increased user experience.

3 ELICITATION STUDY

To investigate **RQ1: How can gamification elements – such as points, badges or leaderboards – be transformed to the physical space?**, we conducted a qualitative elicitation study in our lab. This approach is inspired by prior work, primarily in the field of gesture elicitation, employing users to define input systems such as work by Kerber et al. [17] or Wobbrock et al. [47]. We introduced participants to six commonly used gamification elements and asked them about their ideas on how these elements could be realized with physical objects.

The set of gamification elements we used, was based on literature reviews by Hamari et al. [13] and by Seaborn and Fels [40]. We included the most commonly used gamification elements, i.e., Points, Social Competition, Social Collaboration, Virtual Character, Challenge and Unlockables. As a starting point, we decided to use marbles as physical objects since previous work used them as a metaphor for tangible user interfaces [41]. Additionally, marbles are inexpensive, do not have a specific use to them (which aims to reduce potential bias to participants' ideas), allow for creativity, and are not inherently valuable. Marbles also provide a huge variety of features, i.e. they have color, are collectible, make sound, have weight, can be of varying materials, are graspable, can hold paint, etc.

3.1 Materials

We used physical objects related to marbles, which participants could use to illustrate their ideas. More specifically, the following materials were provided to participants (see Figure 2):

Containers: Participants had the chance to use different kinds of containers and boxes. For instance, *plastic cups* were provided alongside *plastic boxes* and *canvas tote bags* in varying sizes.

Marble track: We also provided several objects which can be used as part of marble tracks. More specifically, *marble track pieces* in different colors and shapes were provided as well as flexible and rigid *tubes* and a *metal track*.

Marbles: We provided a wide range of marbles, differing in their color, size and material. *Wooden marbles* in different colors were provided alongside *glass marbles* in different colors and sizes. We also provided *magnetic marbles* as well as *plastic marbles* in varying sizes and colors.

3.2 Procedure

After giving informed consent and explaining the goal of the study, participants were asked to familiarize themselves with the material that was provided to them. They could take as much time as they wanted to interact with the different objects. To support participants exploring the design space and think of different creative ways in which properties of marbles and the aforementioned physical objects can be leveraged, we asked them how the materials can be used to provide information and feedback and in which ways they can be interacted with.

To enhance the comparability of the information provided to participants, we had a checklist of properties of marbles. We made sure that all properties were either mentioned by participants or suggested by the researcher conducting the study. The checklist included the following properties: Marbles can roll, have different colors, different sizes, different weights, materials, and tactile feelings. They make sounds, can be collected, can be thrown, can be stacked, are portable, can serve as tokens or currency.

Afterwards, the concept of gamification was introduced to participants, based on the definition by Deterding et al. [6]. We gave examples for gamification in various domains. Participants were encouraged to ask further questions. In addition, to encourage participants to reflect on their own experiences with gamification, we asked them about their own examples of gamification.

As a next step, the main part of the study started. Here, we provided six storyboards explaining gamification elements in the context of physical activity to participants (one by one). The storyboards did not contain any textual information about which gamification elements were depicted. Also, we printed out textual descriptions of gamification elements (e.g. *the person in the storyboard is motivated by the possibility to compete with others*, explaining social competition). The storyboards and textual descriptions have been used in previous research and were shown to be comprehensible and successful in depicting and explaining gamification elements [2]. Both can be found on figshare[1]. For each storyboard, participants were asked to find the corresponding textual description, and describe what is shown on the storyboard, to make sure that they understood the gamification element correctly. After each storyboard, the participants were asked how they would implement the given gamification element by using the marbles, containers and marble track objects provided to them. Participants were encouraged to think aloud and use the materials to illustrate their ideas. We also provided sketching material, which could be used to further explain the ideas. This step of the study was conducted as a semi-structured interview, in which one researcher asked participants about reasons for choosing a certain object. Also, participants were asked to expand upon ideas. Figure 3 shows a participant interacting with the provided material to come up with ideas on how to realize certain gamification elements. After completing all six gamification elements, participants were asked to provide demographic data, were debriefed and received a 10 Euro amazon voucher as compensation. The study has been reviewed and received ethics clearance through an institutional Research Ethics Committee[2]. It took approximately 90 minutes to complete.

[1]https://doi.org/10.6084/m9.figshare.16831864.v1, last accessed October 21, 2021
[2]https://erb.cs.uni-saarland.de/, last accessed October 21, 2021

Fig. 3. A participant interacting with the provided materials (left) and the study supervisor (right)

3.3 Method

The study was video-taped and videos were manually transcribed. The transcription contained both spoken answers of participants as well as relevant gestures they performed when explaining their ideas.

We first conducted a content analysis [15] to learn which physical objects were used by participants. Two independent coders inspected the transcriptions of participants' answers in the same order and met after each participant to discuss and merge their codes by discussing differences and overlaps. This process was followed to establish a code book, containing rules for when a certain code was applied. To investigate the generalizability of this code book, a third coder, who was not involved in the code book development, was given the code book to analyze 25% of the transcripts, i.e. 18 gamification elements. We then calculated the inter-rater agreement between the third coder and the codes which the first and second coder agreed upon.

After understanding *which* objects were used to mimic certain gamification elements, we analyzed *how* these physical objects were used within each gamification elements. This was done by one researcher of the team who conducted an inductive thematic analysis [4] on the transcripts for each gamification element.

3.4 Results

We recruited 12 participants (8 self-identified as male, 4 as female; all participants were between 20 and 30 years old). Participants were recruited from the campus, and were compensated with an Amazon voucher worth € 8. The majority (9) of the participants were German, and the remaining 3 were from Pakistan, Kazakhstan, and China. On a Likert scale from 1 (Strongly disagree) to 5 (Strongly agree), they self-reported as gaming-affine (M=4.08, SD=1.08) and were rather neutral regarding their passion for video games (M=3.08, SD=1.38) and how frequently they played such games (M=2.92, SD=1.44). To find out which physical objects were used for which gamification element, we analyzed the frequency of codes provided by the coders. We used Cohen's Kappa to calculate the inter-rater agreement between the third coder and the codes which the first and second coder agreed upon and found it to be κ=0.70, which is considered as substantial [26].

The list of codes and their frequency for each gamification element can be seen in Table 1. In the following, we will discuss the most relevant physical objects for each gamification element (we considered such objects as relevant, which

Code	**Explanation**	**Poin.**	**Comp.**	**Coll.**	**ViCa.**	**Chal.**	**Unlo.**	**Sum**
Marble Size	the size of the marble is altered	5	5	2	5	5	3	25
Marble Color	the color of the marble is altered	7	0	6	1	1	1	16
Special Marble	features of the marble are altered	6	5	3	**10**	8	10	**42**
Superball	the superball is used	0	0	1	5	1	1	8
Magnetic Marble	magnetic marbles are used	5	1	2	4	3	3	18
Rigid Tube	the rigid tube is used	6	**9**	6	2	**9**	4	**36**
Container	a non-specified container is used	**9**	5	5	2	7	3	31
Cup	a cup is used	1	3	2	0	4	1	11
Marble Track	a marble track is used	7	8	**7**	6	7	**11**	**46**
Track Piece	a track piece can be unlocked	2	1	2	4	1	10	20
Metal Track	the metal track is used	3	0	1	1	1	1	7
Flexible Tube	the flexible tube is used	2	1	1	1	1	1	7
Canvas Tote Bag	the canvas tote bag is used	3	4	0	2	1	1	11

Table 1. Codes derived from the content-analysis, a brief explanation and their frequency for each gamification element. *Poin.*=Points, *Comp.*=Competition, *Coll.*=Collaboration, *ViCa.*=Virtual Character, *Chal.*=Challenge, *Unlo.*=Unlockables

were used by at least half of the participants (six)) and provide insights on how participants have used them. We use these results to establish design recommendations (DR) for each gamification element, which can inform the design of systems using physical objects to mimic gamification elements.

3.4.1 Points. For *Points*, it can be seen that the most relevant objects were *Container*, *Rigid Tube*, *Marble Color*, *Marble Track* and *Special Marble*.

Based on the thematic analysis, we found that participants mostly used containers and the rigid tubes to store collected marbles, such that they could quickly see how many points they have collected (we labeled the theme that emerged *points accumulation and storage*). Thus, we establish design recommendation **DR1: When using points, provide containers that only allow a single layer of objects, to enable users to quickly see how many points they have gathered**.

Another theme that emerged was *using marble characteristics such as size and color to indicate value*. We found that special marbles (including marbles in different sizes and colors) were frequently used to indicate enhanced value/more points. This is important because the physical space to store marbles is restricted. Thus, we establish **DR2: Extraordinary objects can be used to represent a higher number of points, to alleviate space restrictions in the physical world**.

The marble track was mostly used for means of transportation, i.e. to transport the marbles into the containers. Thus, the marble track is not particularly relevant to the gamification element as such, but more to the overall system.

3.4.2 Social Competition. Based on the coding process, we found that the most relevant physical object in the context of *Social Competition* was *Rigid Tube*, followed by *Marble Track*.

The theme *tube-based leaderboard* emerged. The rigid tube made of acrylic glass was mostly used to store marbles, one tube for each person, allowing for easy comparison between participants to compare their scores. Similar to before, the marble track was used to transport the marbles into the tubes. We derive **DR3: A (transparent) container per person can be used to show the score of each competitor and thus allow for social competition**.

3.4.3 Social Collaboration. Similar to *Social Competition*, *Marble Track* and *Rigid Tube* were the most frequently used physical objects. In addition, *Marble Color* was coded for half of the participants. However, the way participants used these objects differed: In contrast to *Social Competition*, the theme *one Tube for Collaborative Progress* emerged, meaning that the transparent rigid tube was mostly used as one shared tube to store the collected marbles of all participants. Thus, participants share the goal to fill the tube. This leads to **DR4: A shared (transparent) container can be used to show the collective score of all users and reflect the progress towards achieving a shared goal**.

In addition, the thematic analysis lead to the theme *colored marbles to represent individual users*, meaning that participants utilized the color of marbles to reflect the progress of participants, i.e. each user has marbles in a specific color such that the contribution of each user can be visualized. Thus, we establish **DR5: Objects of different colors can be used to reflect the contribution to a progress of individual users in social collaboration**.

3.4.4 Virtual Character. *Special Marble*, followed by *Marble Track* were the most frequent codes for this gamification element. One theme that emerged was labeled *utilizing characteristics of marbles to reflect the state of the virtual character*. Special marbles, i.e. marbles with uncommon sizes, colors or materials etc. were used to reflect the state of the virtual character. The main idea was to use very common marbles which become more and more special when the user performs well. Based on these insights, we derive **DR6: Features that make an object special can be used to reflect the state of a virtual character and thus the performance of the user**.

Interestingly, the marble track was used completely differently in the context of the virtual character. The theme *marble track as virtual character* was derived. Participants considered the whole marble track as the virtual character and suggested to reflect the state of the virtual character by the length of the marble track. The idea was to expand/collapse the marble track, depending on the performance of the user. This leads to **DR7: The state of the virtual character can be tied to the length or complexity of a physical object**.

3.4.5 Challenge. For this gamification element, it can be seen that *Rigid Tube*, *Special Marble*, *Container* and *Marble Track* were the most relevant objects used.

Related to the rigid tube and containers, one theme that emerged was *progress towards goal*. Participants used a tube or container which gets filled with marbles, thus providing feedback towards completing the challenge, i.e. reaching the top of the container/tube. Thus, we derive **DR8: Challenges can be reflected by using a container which fills with objects to visualize the progress towards mastering the challenge**.

A second theme was *special marbles as rewards*. This theme was more focused on how mastering a challenging can be rewarded. Participants frequently mentioned that mastering the challenge is rewarded by a marble that is tied to this achievement. This marble needs to be special, e.g. because of its size, material or color. This is summarized in **DR9: Mastering a challenge can be rewarded by using extraordinary objects, reflecting this achievement**.

In line with previous findings, the marble track was mostly used for transportation purposes, i.e. to transport marbles into the containers/tubes.

3.4.6 Unlockables. Relevant physical objects included *Marble Track*, *Special Marble* and *Track Piece Unlockable*.

Here, two major themes emerged: *receiving special marbles as reward* and *receiving objects which can be used to expand the marble track as reward*. In the former, participants used special marbles, e.g. marbles in an extraordinary color or size, as unlockables, leading to **DR10: Unlockables can be realized by using physical objects with special characteristics**. In the latter, physical pieces, which could be used to expand the marble track, were used as unlockables.

This included track pieces but also bells ringing when marbles roll or special track pieces such as ramps. It leads to **DR11: Decorative objects to enhance or expand a physical artefact can be rewarded as unlockables**

3.4.7 General Design Considerations. Besides the gamification elements related themes, also more general themes emerged, such as *enjoy rolling marbles*. Participants frequently stated that they would like to use the marble track for transportation. They emphasized, that they enjoy to see the marble rolling and that they like to hear the sound of rolling marbles. Related to this, *marble track extensions* emerged, meaning that participants mentioned that they would like to add bells making sound when marbles pass through them or marble machine splitters to the marble track. Thus, we derive **DR12: Consider adding elements providing visual or auditory sensation to the physical gamification system**.

4 PROTOTYPE

To investigate the perception of transforming virtual gamification elements into their physical counterparts, we built and implemented a prototype based on the design recommendations established in the elicitation study.

4.1 Gamification Elements

We decided to realize the gamification elements *Points* and *Leaderboard*. This decision is based on the fact that points and leaderboards are the most frequently used gamification elements [13, 40] and because the ideas proposed by the participants are technically feasible for these two gamification elements. Thus, as a first steps towards analyzing the effects of physical gamification, we considered these two core elements to be appropriate.

We based the realization of points and a leaderboard as physical gamification elements on the respective design recommendations. Points were realized using colored, wooden marbles. The colors were used to distinguish different users on the leaderboard (**DR5**). The collected points (marbles) were stored in a transparent tube made of acrylic glass, such that users can easily see how many points they have collected (**DR1**). Therefore, each user has their own transparent tube (**DR3**) in which marbles of their color were stored. Since we plan to do a lab study with a limited time frame, we did not realize **DR2**, since we did not expect to run into space issues (a tube can fit 20 marbles).

4.2 System Design

Following **DR12**, the whole system can be seen as a marble track (see Figure 4). We realized four marble magazines (see Figure 1b; two are located in the front of the system, two in the back), in which marbles of different colors can be stored. The magazines are are covered with acrylic glass, to enhance visual sensation (**DR12**). Below the marble magazines is a merger. This merger is responsible to take a marble out of the four magazines and move it to the splitter units. The splitter units (see Figure 1c) are responsible for distributing the marbles to the designated output tube (the output tubes cannot be seen on Figure 4 but are shown on Figure 1d). Similar to the marble magazines, the splitters are covered by acrylic glass, such that users can follow the way of a marble to the respective output tube. We realized three splitters, which can distribute marbles into four output tubes. Both the merger and the splitter units are realized by using stepper motors, which are controlled by an Arduino Mega. The whole system is realized in a modular way, i.e. every unit (magazine, merger, splitter) can be removed or added, allowing to extend the system easily.

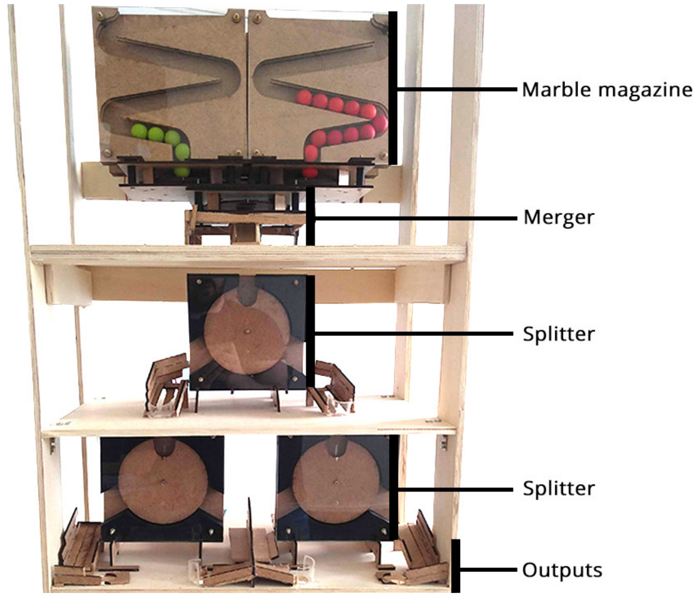


Fig. 4. Overview of the physical prototype realizing points and a leaderboard and its different parts.

4.3 Implementation

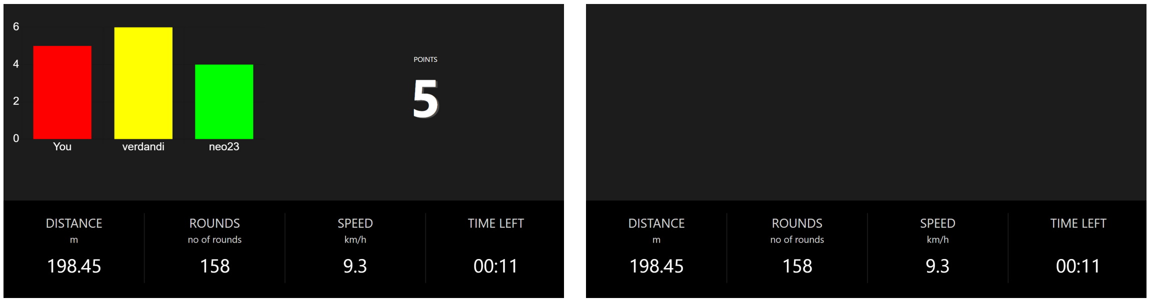
The Arduino provides a serial higher-level interface, which can be used to move a certain marble from one of the marble magazines into a designated output tube. Besides this higher-level command, the interface also allows to control specific units individually and offers a calibration mode, which can be used to calibrate the position of the stepper motors to avoid that marbles are getting stuck. The Arduino is connected to a personal computer which runs a NodeJS webserver. The webserver is added as an abstraction layer to the serial interface and provides a restful API, which can be accessed by using web technology. Whenever a call to the webserver is made over the REST API, the webserver redirects the call through the serial interface (USB) to the Arduino, which executes the respective command.

5 LABORATORY STUDY

To investigate **RQ2: Does physicality enhance the perceived meaningfulness of gamification elements?**, we conducted a laboratory study in which participants were given the chance to interact with both a virtual and a physical gamification system. For the latter, we used the prototype described in Section 4. To compare this physical system against virtual gamification, we implemented a web-based prototype, providing the same set of gamification elements as the previously described prototype, i.e. points and a leaderboard. We acknowledge that it is hard to fairly compare two systems differing in the feedback modality (virtual vs. physical). However, to explore the concept of physical gamification and to benchmark its perception and effects, we deemed a comparison to a virtual gamified system important.

5.1 Task

Since the elicitation study (see Section 3) was contextualized in the domain of encouraging physical activity, we used the same context for the laboratory study. Therefore, we used a stationary bike which we equipped with an Arduino



(a) Graphical User Interface and virtual gamification elements used in the Virtual Gamification condition

(b) Graphical User Interface without gamification elements used in the Physical Gamification condition

Fig. 5. Graphical User Interfaces for the conditions of the laboratory study

and a reed switch to track the number of rounds and thereby the distance cycled. The number of rounds was sent via the serial interface to a desktop computer, where a NodeJS webserver was running. After receiving the number of cycled rounds, the webserver distributed the data to both physical and virtual gamification systems using websockets. The gamification concept was kept simple. For every 30 rounds cycled, participants were rewarded 1 point. The leaderboard in both the physical and the virtual conditions (see below) showed the current user, next to two fictitious users on the leaderboard. In line with Mekler et al. [28], we decided to use fictitious users to not introduce any bias on the performance or perception of participants. The amount of points of the two fictitious users was determined on the basis of an informal pre-test, such that the second rank was easily and the first rank a bit harder to achieve. The fictitious user on the first rank had six, the fictitious user on the second rank had four points. The colors (red for the participant, yellow for the second rank, green for the third rank) and the amount of points (marbles) of each rank was the same in both the physical and the virtual system.

5.2 Conditions

The study was performed in a within-subject manner, consisting of two conditions. In the **Virtual Gamification** condition, a website was shown on a display in front of participants, where they could see the distance cycled, the number of rounds completed, their speed, the time left as well as the number of points collected and their position on the leaderboard. The design and realization of the gamification elements were based on the design of Mekler et al. [28], who used points and a leaderboard in the context of a web platform for image tagging and showed that these gamification elements had an effect on the performance of participants. In the **Physical Gamification** condition, no virtual gamification elements were activated but the website still showed the distance cycled, the number of rounds completed, the current speed and the time left. However, the gamification elements (points, leaderboard) were replaced by their physical counterparts. We made sure that the visual appearance of the virtual gamification elements matched the physical representation, i.e. the color of participants' score in the virtual leaderboard was the same color as their marbles. Figure 5 shows the Graphical User Interface of both conditions, which was shown on the display.

5.3 Apparatus

During the experiment, participants were sitting on a chair in front of a display, which was placed on a table. Right behind the table, the physical gamification prototype was placed, such that it was in the field of view of the participants. Under the table, the stationary bike was placed and was arranged such that participants could comfortably cycle.

5.4 Hypotheses

We investigated the following hypotheses:

H1: Participants perceive the *Physical Gamification* system as more meaningful than the *Virtual Gamification* system

H2: Participants perceive the *Physical Gamification* system as more enjoyable than the *Virtual Gamification* system

H3: Participants perceive the *Physical Gamification* system as more persuasive than the *Virtual Gamification* system

H4: The distance cycled is higher in the *Physical Gamification* condition than in *Virtual Gamification*

H1 is based on the assumption that the physicality, i.e. the fact that the rewarded points exist in reality, add value and thus meaningfulness [10, 50] to the physical gamification system. **H2** follows a similar argumentation. We expect that the enhanced playfulness of physical objects or physical interfaces [50] leads to an increased enjoyment of the activity users are performing. Similarly, **H3** is based on the assumption that the enhanced meaningfulness leads to an enhanced perceived persuasiveness. **H4** is a direct consequence of **H1–H3**; we assume that the increased meaningfulness, enjoyment and persuasiveness has an effect on intrinsic motivation [38] and thus should lead to an increased performance.

5.5 Procedure and Method

After giving informed consent, participants were asked to provide demographic data. Next, one of the two conditions followed. The order of conditions was randomized to reduce learning- and carry-over effects [36]. In each condition, participants were asked to cycle the stationary bike for two minutes. This duration was kept rather short to minimize fatigue effects which might bias performance results related to **H4** and because performance was not the main focus of our second research question. As explained before, participants received either virtual points to climb up the virtual leaderboard in the **Virtual Gamification** condition or received physical points in the form of marbles to climb up the physical leaderboard in the form of three different tubes made of acrylic glass, in which the marbles were automatically distributed as described in Section 4, in the **Physical Gamification** condition.

After cycling for two minutes, participants were asked to fill out a survey to assess their perceived meaningfulness of the activity, their enjoyment and the perceived persuasiveness in each condition. Perceived meaningfulness of the gamification feedback (cf. **H1**) was measured with a 6-item scale adapted from May et al. [24]. Participants were asked to rate how strongly they agreed with each item (e.g. *the feedback provided by the system was worthwhile*; *the feedback provided by the system was personally meaningful to me*) using 5-point scales (1=strongly disagree, 5=strongly agree). Intrinsic motivation and enjoyment (cf. **H2**) was measured using the validated short German version of the Intrinsic Motivation Inventory [25, 37, 46], measured on 7-point scales. The instrument was translated to English by a professional, bilingual translator. To measure perceived persuasiveness (cf. **H3**), we adapted the perceived persuasiveness scale by Drozd et al. [9] in the same way as was done by Orji et al. [32]. The scale consists of four items being measured on 7-point Likert scales. To investigate **H4**, we measured the distance cycled in each condition.

	Virtual Gamification	Physical Gamification	Diff. sig.
Meaningfulness [scale from 6-30]	M = 22.33, SD = 5.42, Mdn = 21.50	M = 26.25, SD = 4.83, Mdn = 26.50	p = 0.028 Z = -3.06
IMI Enjoyment [scale from 3-21]	M = 15.92, SD = 2.39, Mdn = 16.00	M = 16.17, SD = 1.95, Mdn = 16.00	-
IMI Competence [scale from 3-21]	M = 16.00, SD = 2.92, Mdn = 14.50	M = 15.92, SD = 4.01, Mdn = 16.50	-
IMI Pressure [scale from 3-21]	M = 10.83, SD = 6.13, Mdn = 11.00	M = 10.42, SD = 4.93, Mdn = 10.50	-
IMI Choice [scale from 3-21]	M = 16.67, SD = 2.71, Mdn = 16.50	M = 16.75, SD = 2.99, Mdn = 17.00	-
Persuasiveness [scale from 4-28]	M = 18.50, SD = 6.40, Mdn = 17.00	M = 21.58, SD = 3.73, Mdn = 22.50	p = 0.038 t = -2.35
Cycled Rounds	M = 206.08, SD = 58.74, Mdn = 198.00	M = 206.50, SD = 40.67, Mdn = 199.00	-

Table 2. Dependent variables of the laboratory study for the Virtual Gamification and the Physical Gamification conditions and results of paired samples t-tests / Wilcoxon signed rank tests ("Diff. sig.") comparing them.

After completing both conditions, participants were asked to decide which system they prefer. Also, a free-text field was provided, in which participants were asked about their thoughts on both systems to learn more about the reasons why participants prefer one system over the other. The free-text fields were analyzed by conducting an inductive thematic analysis [4]. The study has been reviewed and received ethics clearance through an institutional Research Ethics Committee[3]. It took approximately 15–20 minutes to complete and was compensated by a 3 Euro amazon voucher. The hypotheses were evaluated using paired t-tests or Wilcoxon signed rank tests (when the assumption of normality was not met).

5.6 Results

We recruited twelve participants for the study, as chosen based on an a-priori calculated power analysis. We expected that the effect size between a physical and virtual system is similar to the effect sizes presented in previous research [50]. Thus, we expected a large effect size of d=.8, aimed for a power of 80% and relied on a one-tailed test since our hypotheses were directional, revealing a minimum amount of 12 participants and an actual power of 83%. Of those, six self-reported their gender as female, six as male. All participants were between 18 and 31 years old. Participants were from Germany (8), Kazakhstan (2), Luxemburg and India. They self-reported as gaming-affine (M=3.92, SD=1.24) and slightly agreed to having a passion for video games (M=3.66, SD=1.38) and to frequently playing such games (M=3.92, SD=1.31).

5.6.1 Perception and User Experience. When analyzing the perceived meaningfulness of both systems, it can be seen that physical gamification leads to a significantly enhanced perceived meaningfulness (p = 0.028, Z = -3.06; see Table 2). Thus, we derive result **R1: The physical gamification system was perceived as significantly more meaningful than the virtual counterpart**. Notably, the physical gamification system reached an average meaningfulness score of 26.25/30, indicating that participants felt a high sense of personal relevance and considered the physical gamification feedback as worthwhile.

[3]https://erb.cs.uni-saarland.de/, last accessed October 21, 2021

However, no significant effects were found for the factors of the IMI, i.e. enjoyment, competence, pressure or choice. Based on the descriptive data, it can be seen that **R2: Both the virtual and physical system was perceived as enjoyable** (with a mean score of 15.92 and 16.17 out of 21, respectively). Although this result does not support **H2**, it shows that the virtual gamification system was perceived as enjoyable, which adds to the validity of the virtual system and the realization of the virtual gamification elements. Although the remaining IMI factors do not differ significantly, they indicate that both systems were positively perceived and seemed to provide a gameful, supportive experience.

Regarding the perceived persuasiveness, a significant difference could be found. As revealed by a paired t-test, **R3: The perceived persuasiveness is significantly higher in the Physical Gamification condition than in Virtual Gamification** ($p = 0.038$, $t = -2.35$; see Table 2).

5.6.2 Performance. When analyzing the number of cycled rounds in the two-minutes session in each condition, no significant effects were found. As can be seen in Table 2, the number of rounds in the Physical Gamification condition is almost the same as in Virtual Gamification.

5.6.3 Preferences and Reasons. Regarding the preferences of participants, we found that 10 participants preferred the physical system over the virtual system, while two preferred the virtual system over the physical one. Thus, we derive **R4: More than 80% of participants preferred the physical gamification system over the virtual gamification system**. Next, we provide more insights on what participants liked or disliked about both systems.

A main reason why the physical gamification system was preferred was because of its *persistence*. Participants reported that they liked to see their progress and the progress of others ubiquitously. They also stated that the physical representation of points increased the *awareness* of their performance and allowed them to better relate to the points. Another frequently mentioned reason is related to the *existence of points in the real world.* Participants reported that they were motivated by the fact that they were given real, physical rewards instead of purely virtual ones. They considered the physical points (i.e. marbles) an unimpeachable proof of their performance and emphasized that this cannot be achieved by using virtual points. Also, participants enjoyed watching the *movement of the marbles* from the marble magazine to the respective tube.

Besides the positive aspects explained before, participants also commented on aspects of the physical system which could be improved. Some participants suggested to decrease the time it takes to distribute the marble from the magazine to the tube (in the current prototype this process took approximately 6 seconds), such that the feedback is tighter coupled to the trigger (i.e. completing 30 rounds). Also, a common criticism was that the *physical system is impractical* to use it at home (too big, too heavy) and thus should be made more lightweight and smaller.

6 DISCUSSION AND LIMITATIONS

In this paper, we investigated how gamification elements can be transformed to the physical world (**RQ1**) and whether such physical gamification elements could help to solve the problem of gamification being perceived as meaningless (**RQ2**) in the course of two user studies. The results of these studies will be discussed in the following.

Based on the elicitation study, we found in general that virtual gamification elements can be represented using physical objects. Our results show that the different materials that we provided to participants (containers, marble track, marbles) were used differently across gamification elements. Based on a content analysis, we were able to shed light on which physical objects were used for which gamification element (see Table 1). To better understand, how the physical objects were used within each gamification element, an inductive thematic analysis was performed. This analysis revealed that the way of utilizing the physical objects differed across gamification elements. We used both perspectives to derive design recommendations for systems using physical objects to realize concepts of gamification elements. These design recommendations not only guided the design of the prototype that we realized to evaluate our second research question, but could also be used in future work to inform the design of physical gamification systems. As a limitation, it should be noted that we decided to use physical objects related to marbles. This decision was based on previous work using marbles as a metaphor for tangible user interfaces [41] and because marbles are inexpensive, do not have a specific use to them (which might introduce a bias to the participants' ideas), allow for creativity, and are not inherently valuable. However, we would like to acknowledge that this decision also limits the generalizability of our findings and should be considered. Similarly, the specific selection of physical objects provided to participants unavoidably has an effect on the ideas and solutions participants come up with. Although we aimed at providing a wide range of different materials, this limitation should be taken into account when building upon the results of the elicitation study. Consequently, due to the novelty of this approach, we consider our results as a starting point of how virtual gamification elements can be transformed into their physical counterparts and thus contribute answers to a specific shade of **RQ1**, which should be expanded in future work.

After realizing a technical prototype, we were able to conduct a laboratory study to investigate the second research question. In this study, we found that physical gamification is perceived as significantly more meaningful than the virtual gamification system (**R1**). This provides evidence for **H1: Participants perceive the *Physical Gamification* system as more meaningful than the *Virtual Gamification* system**. In the context of the debate on the missing personal relevance and meaning of gamified systems [3, 30], this result shows that using physical objects has great potential to make gamified systems more relevant and relatable to users. On a more abstract level, this result also contributes valuable insight to the ongoing personalization efforts in gamification research [29], which at their core aim to make gamification elements more personally relevant to users.

In contrast to **H2: Participants perceive the *Physical Gamification* system as more enjoyable than the *Virtual Gamification* system**, we did not find any difference in the perceived enjoyment across conditions (**R2**). A potential reason might be that the underlying game mechanic in both systems was the same, since the same gamification elements (points and a leaderboard) were used. Although these gamification elements differed in their physicality or virtuality, they might have evoked similar feelings related to enjoyment. Following this reasoning, the absence of an effect on the enjoyment factor of the IMI supports the comparability of both the virtual and physical gamification systems and shows that both were enjoyable. However, as already stated, we would like to acknowledge that the virtual and physical systems are not fully comparable. We discussed this issue extensively before conducting the study. While we had ideas relating to using Virtual Reality or a virtual representation of the physical system, we came to the conclusion that such comparisons would not allow us to draw conclusions about how our system is perceived, compared to how gamification is being used today. In this paper, our goal was to investigate whether physical gamification has potential to increase the perceived meaningfulness of gamification. Based on our study, we could indeed show that such a physical system has great potential, when comparing it to a conventional gamification system. What we cannot say for sure is whether the physicality was the deciding cause. Since both systems were perceived as enjoyable (both scoring considerably high on the enjoyment factor of the IMI), it seems like the virtual gamification was successful and other factors, such as the physicality, might have led to the increased meaningfulness and persuasiveness. However, this findings needs further consideration in future work.

In addition, we found that the perceived persuasiveness is significantly higher when using physical gamification elements (**R3**). This adds support to **H3: Participants perceive the *Physical Gamification* system as more persuasive than the *Virtual Gamification* system**. The fact that ten out of twelve participants preferred the physical over the virtual gamification system (**R4**) aligns well to the increased meaningfulness, perceived persuasiveness and the high enjoyment. However, in terms of performance, we could not find a significant difference and thus could not find supporting evidence for **H4: The distance cycled is higher in the *Physical Gamification* condition than in *Virtual Gamification***. Potentially, this is due to the short cycling duration of two minutes, which might have not been enough time to find differences in the cycled distance. Another reason might be related to the fact that the gamification elements, regardless of their physicality or virtuality, introduced goals. According to Goal Setting Theory [23], these motivate people by introducing a state of tension that activates actions. Nevertheless, the short interaction time with both systems together with the study being conducted in a laboratory should be considered as limitations, since this potentially might have led to novelty effects. Especially the short cycling duration should be considered in this regard. Therefore, in-the-wild user studies over a longer time-span should be conducted in the future. Such user studies would also allow to assess whether the increased perceived persuasiveness and meaningfulness of physical gamification elements persists over time. Moreover, it should be noted that participants were skewed regarding their age–our sample consisted mostly of young people. However, to generalize our findings, more heterogeneous samples and larger sample sizes should be studied in future work.

7 CONCLUSION

In this paper, we contribute the first systematic exploration of physical gamification, i.e. realizing gamification elements such as points and leaderboards with physical objects, as far as we know. We first investigated *how* virtual gamification elements can be transformed into their physical counterparts by conducting a qualitative elicitation study in the laboratory (N=12). Based on the results, we derive specific recommendations on how to realize the most commonly used gamification elements in the physical world. Next, we built upon these recommendations to realize a mature technical system, which implements the gamification elements points and leaderboard in a modular way. As a third contribution, we used this prototype to investigate *whether* physical gamification elements could help to bridge the problem of gamification being perceived as meaningless by evaluating its perception in a laboratory study and comparing it against a virtual counterpart. Our findings from both user studies show that transforming virtual gamification elements to their physical counterparts is conceptually as well as technically feasible. Also, we found evidence that physical gamification is perceived as significantly more persuasive and meaningful. These findings suggest that using physical objects to realize the concepts of gamification elements has great potential to make gamification more personally relevant to users and thus enhance the persuasiveness, meaningfulness as well as the user experience of gamification.

Future work could build upon our findings and explore the field of physical gamification more broadly. More specifically, future work should investigate different domains (besides physical activity), different physical objects to realize gamification elements (besides marbles) and other gamification elements besides points and leaderboards. Also, studies over a longer time-span should be conducted to get more insights on the impact of a potential novelty effect, which might bias the results of laboratory studies. We also suggest to recruit more participants to investigate potential effects which were smaller than we could find with our sample size.

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