# Experiverse: Exploring an experiment-based gamification application for motivating children to science learning in an informal setting

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## ABSTRACT

Science learning at schools often lacks relevance and connection to real life; therefore, children find it challenging to apply their knowledge and may gradually lose motivation and interest in science. Gamification demonstrates a promising potential to engage children in science learning. However, little work has explored how to develop such gamification applications for them. This paper presents Experiverse, an experiment-based gamification application we developed for children's science learning in informal settings. To evaluate the interaction and experience with Experiverse, we collected data from 25 children (aged 9-13) from multiple sources, including log data, surveys and interviews. Results indicated that children's motivation significantly correlates with their enjoyment and perceived learning outcome from using Experiverse. In addition, the results revealed that children's perceived learning outcome is significantly positively correlated with the number of view visits on Experiverse. Finally, we discuss the implications for future related research on gamification application development for children.

## KEYWORDS

Gamification, Children, Science Learning, Informal Learning, Mixed Methods

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## 1 INTRODUCTION

Science-learning related subjects are crucial for children at an early age, given the ability of science concepts to teach them how to make observations, collect data, and come to conclusions logically. Previous research shows that children's interest in science tends to decrease or increase between the ages of 10 and 14, depending on their learning foundation and areas of interest [2]. Therefore, there is a need to find ways to maintain children's interest in science and encourage this knowledge and experience. One way to prevent the decreasing interest in science is to make learning more inquiry-based and practical. It has been shown that an inquiry-based activity, such as experimentation, can help children become more interested in science due to being physically engaged in it [26].

Gamification demonstrates a promising potential to motivate and engage children in learning, and its applications in education have become increasingly common in everyday learning for children and young adults. For example, a study by [17] showed that educational game improved their performance. More specifically, Mekler et al. [28] suggested that points, levels, and leaderboards in the educational game as extrinsic motivators were only helpful for promoting performance quantity [28]. These findings suggested the essential role children's intrinsic motivation can play in learning. However, there is no comprehensive and explicit guideline regarding developing gamification applications for motivating children's science education. Still, more work needs to be done to explore how to develop gamification applications for science learning.

Some earlier efforts to apply gamification in education occur in online learning settings. For instance, Minecraft, initially a 3D sandbox game, now has an education edition, where children can learn through trial and error and explore science, computer science, and math. Another example is Numetry, a math game where children between the age of 8-12 can learn mathematics through exploring a game universe of spaceships and avatars, solving missions along the way. In addition, there are many opportunities for learning outside the classroom through trips to science centres and museums, amongst other things [24] and different activities [6]. Science learning in an informal setting is beneficial. For example, informal science education for young children can lead to further participation or a STEM career [2]. Another benefit of informal learning is that it makes learning fun and builds confidence and a feeling of accomplishment for the children using it [10]. However, most existing gamification applications focused on formal classroom settings rather than outside of school. Maybe due to the difficulty of evaluating such a wide range of subjects and everyday learning situations [15], only a few gamification applications leverage the opportunities for children's science learning.

This paper presents Experiverse, an experiment-based gamification application for motivating children to learn sciences in an informal setting. First, we describe the underlying rationale for developing Experiverse in the next section and, in particular, formulated six design requirements (DR1-6; as seen in Table1 ) aiming to use Experiverse as an exemplar for inspiring future-related application development. Furthermore, we report an evaluation study involving 25 children aged between nine and thirteen for two weeks, aiming to answer the following research questions:

**RQ1:** *How did children experience and interact with Experiverse?*

**RQ2:** *How did children perceive their experience using Experiverse for science learning?*

**RQ3:** *Is there any correlation between children's perceived experience and their interactions with Experiverse?*

# 2 BACKGROUND AND RATIONALE OF EXPERIVERSE

## 2.1 Inquiry-Based Science Learning and Experiments

Science education in school is often too formal and lacks relevance and connection to real-life situations. As a result, it has fallen short of sustaining children's engagement to apply the knowledge they learn in school and bridge the gap to everyday life situations [14]. In response to fostering children's interest and motivation, the educational strategy called Inquiry-Based Learning is gaining popularity in the science education [29]. Inquiry-based learning emphasises a self-direct learning process through discovering new knowledge and experimenting with investigating the variables [36]. During this process, experimenting, as a part of the inquiry-based activity, has shown great potential to engage and stimulate children's interest in science. According to [26], unstructured inquiry experiments tend to engage students at high cognitive levels. This is also in line with the study by [12] that hands-on experiments promote students' learning and build on their intrinsic motivation. However, despite the fact that some studies followed inquiry-based learning in science education, there have been minimal changes in the way it is taught [1, 18, 34].

In our case, for the development of Experiverse, we emphasised doing experiments on science learning concepts (**DR1**; see the detailed explanation in the next section and Table1 ). In addition, we incorporated some experiments suggested by Nysgjerrigper (a site for children and young people to learn about research and try to do research themselves) into Experiverse. These creative experiments are primarily designed for elementary school children to trigger inquiry-based learning and make more children interested in various topics, including biology, environment, science, and culture. As van Roy and Zaman [30] suggested, it is vital to align the goal of the learning activity with gamification. Table1 below illustrates how we integrated gamification into the activity of science learning through doing experiments [30].

## 2.2 Gamification and Design Heuristics

Gamification involves incorporating gaming elements (e.g., points, badges, leaderboards, challenges, rewards, feedback, avatars) into nongame contexts [11]. Research on gamification is expanding, particularly in education, due to its success as a motivator in school contexts [25]. For example, gamification enables experimentation and learning through trials, which is a promising feature to engage and encourage students to try again. The stakes of learning through gamified applications are low because it is only possible to learn and progress in some games by experimenting and failing; this is contrary to exams and tests in school, where it is possible to fail; hence the stakes are high [20]. Furthermore, gamification can play an active role in engaging, motivating and helping students connect associating science concepts with real-life situations [2]. The study of Ding et al. [13] suggests that game elements such as badges, feedback, progress bars, and avatars promoted student engagement. Similarly, Brewer et al. [5] also pointed out that points and prizes can motivate students in a lab environment. Based on that, they suggested future research considering increasing challenges and adding narratives when implementing gamification elements in a learning environment.

More specifically, van Roy and Zaman [30] introduced several critical gamification heuristics to address the challenges based on Self-Determination Theory [9]. For example, as shown in Table 1, one should avoid obligatory uses of the system and provide enough meaningful choices to support learner autonomy [30]. Accordingly, we defined the following two design requirements for Experiverse: "Children should have the autonomy to choose different experiments and be able to combine learning through games on the mobile application, and hands-on experimentation in a real-life context" (**DR1**) and "children should be able to choose an avatar and follow a game storyline" (**DR2**). Furthermore, as van Roy and Zaman [30] suggested, one's confidence is built through challenging but manageable goals and positive feedback. Accordingly, in Experiverse, we aimed to meet these two design requirements as follows: "Children should be able to write a hypothesis for the experiment" (**DR3**) and "Children should be able to see what their scores, rewards and progress are and to receive rewards and badges when completing experiments" (**DR4**).

In addition, similar applications within the STEM field have been used as inspiration for Experiverse. For instance, Numetry is a story-and-character-driven mathematics game for 4-7th grade aiming to make mathematics learning fun and exciting through accomplishing missions rather than going through straightforward calculations. Furthermore, go-Lab is a website with a collection of online labs [22] aiming to encourage students to become engaged in science topics through online science labs. However, these similar applications explore gamified learning as an in-app experience, and applications targeting experiments in real-life situations are still largely lacking. The Experiverse aims to trigger children's curiosity, motivating them to acquire knowledge through experiments while making it fun. The novelty of Experiverse compared with other similar

**Table 1: Gamification heuristics (#1-4) proposed by [30] and associated design requirements (DR) for Experiverse**

| Challenge | Heuristics | Associated design principles on Experiverse |
|---|---|---|
| Support learner's autonomy | **#1** Avoid obligatory uses | **DR1**: children should have the autonomy to choose different experiments and be able to combine learning through games on the mobile application and hands-on experimentation in a real-life context |
| | **#2** Provide a moderate amount of meaningful options | **DR2**: children should be able to choose an avatar and follow a game storyline |
| Support learner's competence | **#3** Set challenging but manageable goals | **DR3**: children should be able to write a hypothesis for the experiment |
| | **#4** Provide positive, competence-related feedback | **DR4**: children should be able to see what their scores, rewards and progress are and to receive rewards and badges when completing experiments |
| Other | **#5** Privacy consideration | **DR5**: the application should have security measures such as login to ensure privacy for children |
| | **#6** Child-friendly design | **DR6**: the application should have a suitable colour selection for children |

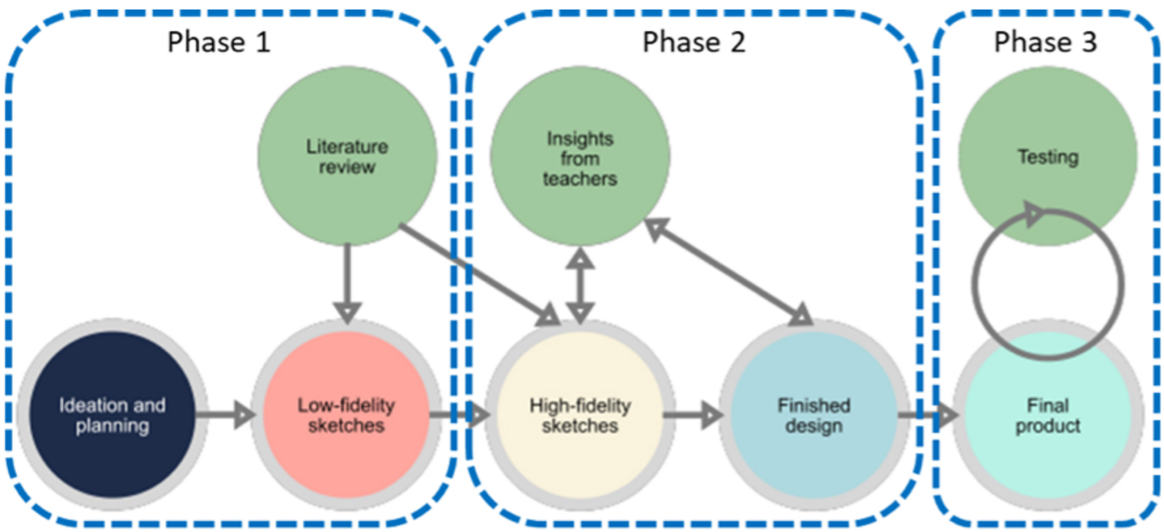


**Figure 1: The iterative design and development process of Experiverse**

applications is reflected in three key aspects: it enables children to do hands-on experiments in a real-life situation as well as learn through the gamified mobile application (see **DR1** in Table1 ), it is featured with an avatar, making the experience has more personal connections (see **DR2**), and it has specific security measures to comply with privacy rules for children (**DR5**).

## 3 DESIGN AND DEVELOPMENT OF EXPERIVERSE

### 3.1 Iterative Design and Development Process

Overall, the iterative design and development process of Experiverse consisted of three phases, as shown in Figure 1 low fidelity sketching and ideation (Phase 1), high fidelity sketching and detailed designing (Phase 2), and the final testing (Phase 3). **Phase 1** concerns the first iteration, which included low-fidelity sketches made using a drawing pad and Adobe Photoshop. The idea was that the player had an avatar to go through the week by doing experiments, visiting museums, reading books, and visiting internet pages. **Phase 2** was based on the outcomes from Phase 1 and consisted of two more iterations that produced high-fidelity sketches with the most crucial functionalities. Finally, **Phase 3** is concerned with testing the app with children in schools.

For example, during Phase 2, we conducted unstructured interviews with teachers (N=3) with questions aiming to understand what interests children in a learning environment from an educator's perspective and gain more inspiration complementary to what we learnt from the literature and validate some ideas for Experiverse. As an illustration, Teacher A suggested that doing experiments is

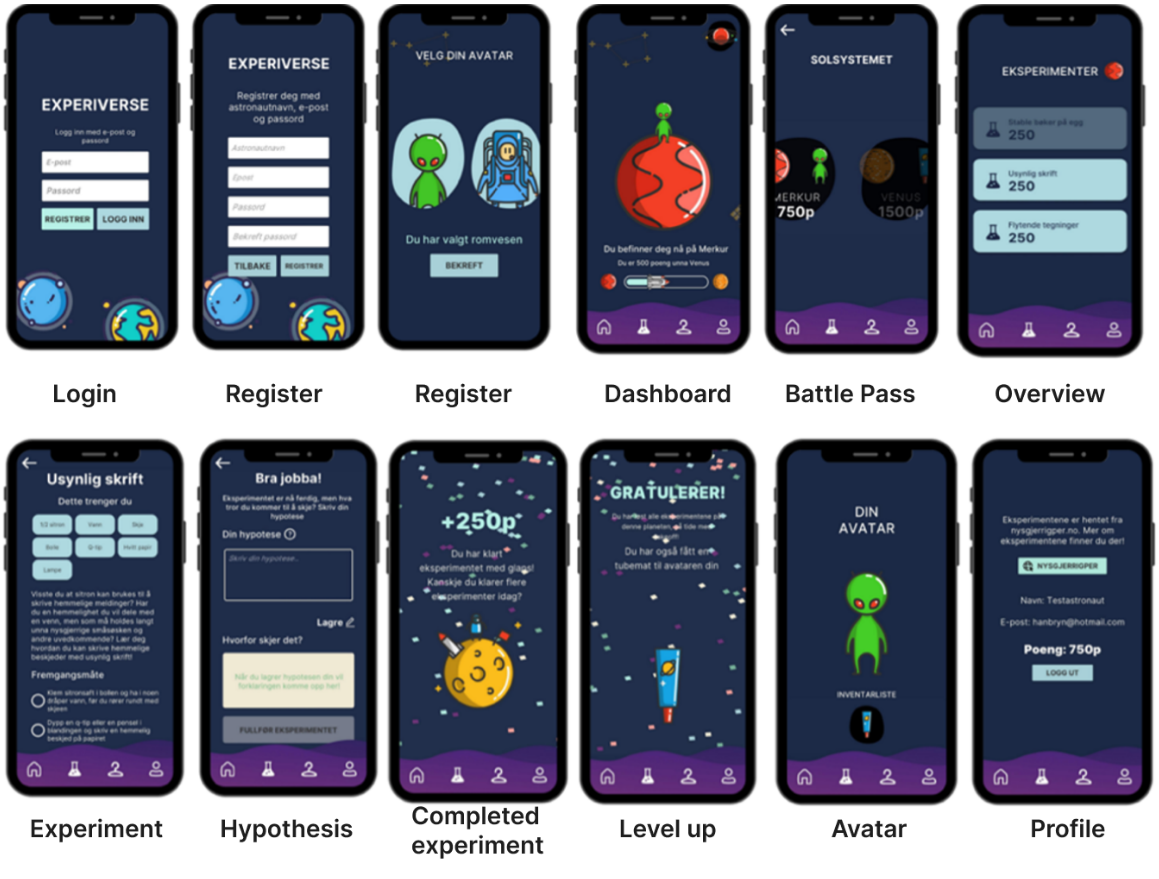


**Figure 2: The main interfaces and crucial functionalities of Experiverse**

among the most intriguing and exciting things children do (**DR1**) and that children would love it if they could change their avatar's clothes and names (**DR2**). Similarly, Teacher B commented that to validate the experiments, one could ask the children to write a hypothesis of what they think would happen and then answer what happened after experimenting (**DR3**). She also mentioned that children are bad at receiving verbal messages, so another feature could be sending notifications and messages in the app (**DR4**, e.g., visualised dashboard). Furthermore, Teacher C expressed that one of the most popular games used for educational purposes, in her opinion, is Minecraft, and for such an app to work, it has to be fun to use and have game elements.

Prior to designing the details of Experiverse, we also searched for other mobile applications for children on Dribbble for inspiration. Furthermore, a colour generator was used to ensure the colours were compatible. To meet the **DR6** concerning the child-friendly design, we selected earthy, playful, and comfortable colours suitable for the children and included them in the final prototype of Experiverse, as seen in Figure 2.

## 3.2 The Final Prototype of Experiverse

In the following paragraphs, we present the main interfaces and crucial functionalities: (1) Login and Register, (2) Home: Dashboard and Battle Pass, (3) Experiment: Overview, Experiment, Hypothesis, Completed Page, and Level Up, (4) Avatar and Profile. Furthermore, we explain how these interfaces and functionalities are linked to the design requirements we identified in Table1.

*3.2.1 Login and Register (DR5).* To achieve **DR5** regarding privacy consideration (see Table1 ), these interfaces of **Login and Register**, as shown in Figure 2, enable children to use their email addresses to register and log in. Furthermore, to enhance the interactivity and personalisation of Experiverse, the user can choose an avatar when logging in for the first time.

*3.2.2 Home: Dashboard and Battle Pass (DR4).* To address the **DR4** concerning providing positive and competence-related feedback, the **Home** view of Experiverse (as seen in Figure 2) provides the children with an overview of their current progress in the application. The **Dashboard** displays which planet they are currently on, their avatar, their score, and how many points they have to gather before taking them to the next planet. The space button (on the top-right of the Dashboard page) leads the children to the **Battle Pass** listing of all the planets in the solar system and what prizes the user will receive when completing all experiments on one planet. This interactive page lets children slide back and forth through the solar system and their belongings' rewards.

*3.2.3 Experiment: Overview, Experiment, Hypothesis, Completed Experiment, and Level Up (DR1, 3, and 4).* The Experiment view has several layers, the Experiment view, the Detailed Experiment view, and the Hypothesis view, as seen in Figure 2. First, children get an **Overview** of the experiment on their current planet, with their belonging scores (**DR4**). To stick to **DR1** to avoid obligatory uses, Experiverse enables children to click on the experiment they want to perform, which takes them to the detailed **Experiment** view. On top of the view, they can find the title of the experiment and a description for each experiment, giving children some background information before they get started. This will provide children with all the things needed for the experiment before continuing to the next step, which is the execution of the experiment. Next, children follow the step-by-step guide before completing the experiment and getting directed to the **Hypothesis** view. According to our defined **DR3** regarding setting challenging but manageable goals, children can write their hypothesis here (i.e., what they think is why the experiment went the way it did). When writing a hypothesis with a sufficient length, children can save it and get an explanation in the explanation field, as seen in Figure 2. This leads the children to the **Completed Experiments and Level Up views** based on their progress (**DR4**).

*3.2.4 Avatar and Profile (DR2).* **Avatar and Profile (DR2).** The **Avatar** view is where to give the avatar an inventory list with the items children received when completing all experiments on a planet (**DR2**), as seen in Figure 2. This inventory list will update when children progress. In addition, the **Profile** view contains a link to the page from which the experiments have been retrieved. By clicking this link, children get redirected to Nysgjerrigper.no, where there is a more thorough explanation of the experiments with images. Examples of experiments include, for example, "make a lemon battery", "make a compass yourself", "make sugar crystals", and others. The Profile also contains the child's name and email address, as well as their total score and a logout button, seen in Figure 2 (**DR4**).

## 4 METHODOLOGY

Overall, this study used a mixed-method sequential explanatory design. In this research design, we first analysed the quantitative data (collected from the survey and log data from Experiverse) to yield a broad comprehension of the research problem. Next, built on the first phase, we analysed the qualitative data (collected from interviews) to help elaborate and delve deeper into the results obtained from the first phase.

### 4.1 Participants

A total of 25 participants, aged between 9 and 13, participated in the study. The study recruited participants by combining convenience sampling and random sampling. The first step was to contact teachers in the circle of friends through Nysgjerrigper and social media. This resulted in recruiting two classes in an elementary school in Viken County in Norway with 18 participants, with seven more added from the other sources. The 25 participants in the study consisted of fifteen boys (60%) and ten girls (40%) and included pupils spread across the different classes in elementary school (M = 5.4, *SD* = 1, min = 4; max = 7), and the ages of the target group (M = 10.96, *SD* = 1.02, min = 9; max = 13). One cinema gift card with a value of 150 NOK was given to each participant upon completion of the study.

### 4.2 Procedure

Prior to the test period, the parents of participating children received a guide either through the teacher or by mail on how their child can download the beta version on their Android or Apple device. The testing period lasted two weeks to ensure that as many participants as possible from the convenience sampling group used Experiverse. After two weeks of user testing at home, the participating children were asked to fill out a survey and asked to participate in a short interview (seven children agreed to be interviewed).

### 4.3 Data Collection

A total of three data sources were collected in this study. First, we collected **log data** that Experiverse captures while children use it. These login data included (a) children's total time (TT) of interacting with Experiverse and other specific achievements on Experiverse, such as (b) experiments completed (EC), (c) battle pass views (BPV), (d) avatar view visits (AVV) and (e) experiment view visits (EVV). Second, we asked children to fill in a **survey** after the testing period of Experiverse to examine their experience of using the application. The survey measured children's experience regarding the three following dimensions: (a) perceived enjoyment (PE) which contains questions regarding the enjoyability and motivation (MO) of using Experiverse inspired by [32, 35], (b) perceived learning outcome of the application (LOA) which included questions regarding perceived learning performance adapted from [8]. Last, seven children were **interviewed** about their experience and perception of gamification in Experiverse after using it to gather qualitative data, triangulate the results, and get a deeper understanding.

### 4.4 Data Analysis

For quantitative data (i.e., survey and log data), Spearman Correlation was used to determine the relationship between the quantitative variables. For the qualitative data, we used the inductive category development described in the qualitative content analysis [27] and the thematic analysis [3, 4]. We iteratively used this technique to develop themes by revisiting the interviews and grouping similar statements.

## 5 RESULTS

### 5.1 Children's Interaction and Experience with Experiverse

The log data contains more fluctuating data as the data is measured in clicks on the different views of the app and time spent in the app in seconds, in contrast to the Likert scales in the questionnaire. For example, one can see in Table 2 that the average use of the app was approximately 20 min and 55 seconds (M=1254.92). Thus, as the standard deviation here is considerable and the range of the observation is vast, it is indicated that the actual use of the app varies a lot amongst the participants, according to the statistics. This is also the case with Experiments completed in the app (EC), where

**Table 2: Descriptive statistics on using Experiverse (based on log data and survey responses)**

| Measurement | Minimum | Maximum | Mean | SD |
|---|---|---|---|---|
| PE | 4 | 7 | 5.44 | 0.91 |
| LOA | 1 | 7 | 4.16 | 1.65 |
| MO | 2 | 7 | 5.3 | 1.43 |
| TT | 281 | 4800 | 1254.92 | 1174.22 |
| EC | 0 | 19 | 3.2 | 3.86 |
| BPV | 0 | 7 | 3.2 | 3.86 |
| AVV | 0 | 12 | 3.72 | 3.8 |
| EVV | 0 | 44 | 13.04 | 9.95 |

Abbreviations: PE – Perceived Enjoyment; LOA – Learning Outcome of the App; MO – Motivation; TT – Total Time; EC – Experiments Completed; BPV – Battle Pass Views; AVV – Avatar View Visits; and EVV – Experiment View Visits.

**Table 3: Spearman correlations between the variables (*Correlation is significant at the 0.05 level, **correlation is significant at the 0.01level)**

| | PE | LOA | MO | TT | EC | BPV | AVV | EVV |
|---|---|---|---|---|---|---|---|---|
| PE | 1 | 0.339 | **0.58**** | -0.12 | 0.15 | -0.09 | -0.3 | 0.18 |
| | | $p > .05$ | **$p = .003$** | $p > .05$ | $p > .05$ | $p > .05$ | $p > .05$ | $p > .05$ |
| LOA | | 1 | **0.52**** | -0.19 | 0.84 | 0.17 | 0.18 | **0.49*** |
| | | | **$p = .008$** | $p > .05$ | $p > .05$ | $p > .05$ | $p > .05$ | **$p = .012$** |
| MO | | | 1 | -0.23 | 0.26 | 0.42 | -0.23 | 0.28 |
| | | | | $p > .05$ | $p > .05$ | $p > .05$ | $p > .05$ | $p > .05$ |
| TT | | | | 1 | 0.31 | **0.52**** | 0.27 | **0.49*** |
| | | | | | $p > .05$ | **$p = .007$** | $p > .05$ | **$p = .012$** |
| EC | | | | | 1 | 0.26 | 0.07 | 0.26 |
| | | | | | | p > .05 | $p > .05$ | $p > .05$ |
| BPV | | | | | | 1 | **0.61**** | **0.64**** |
| | | | | | | | **$p = .001$** | **$p = .001$** |
| AVV | | | | | | | 1 | **0.44*** |
| | | | | | | | | **$p = .02$** |
| EVV | | | | | | | | 1 |

Abbreviations: PE – Perceived Enjoyment; LOA – Learning Outcome of the App; MO – Motivation; TT – Total Time; EC – Experiments Completed; BPV – Battle Pass Views; AVV – Avatar View Visits; and EVV – Experiment View Visits.

some have completed 0 experiments, while others have completed 19, and the average is just above 3 (M=3.20, SD=3.862).

From the survey data, we observe that the overall enjoyment (PE) and motivation (MO) were reported to be high (mean PE = 5.44 out of 7 and mean MO = 5.3 out of 7), but the perceived learning outcome of the app (mean LOA = 4.16 out of 7) was average. This shows that the children enjoyed the app and were motivated to use it; however, they only perceived it to be moderately useful in science learning (see Table2 ).

As seen in Table 3, there is a significant and positive correlation between motivation (MO) and enjoyment (PE) (r (25) = 0.58, $p = .003$) and enjoyment (PE) and perceived learning outcome (LOA) (r (25) = 0.52, $p = .008$). Regarding the log data, we observe the following significant and positive correlations: First, between the total use time (TT) and battle views (BPV) (r (25) = 0.52, $p = .007$). Second, between the total use time (TT) and experiment views (EVV) (r (25) = 0.49, $p = .012$). Third, between the experiment views (EVV) and battle views (BPV) (r (25) = 0.64, $p = .001$). Fourth, between the avatar (AVV) and battle views (BPV) (r (25) = 0.61, $p = .001$). Fifth, between the experiment views (EVV) and avatar views (AVV) (r (25) = 0.44, $p = .02$). Finally, there is also a significant and positive correlation between the number of times experiments were visited (EVV) and the perceived learning (LOA) (r (25) = 0.49, $p = .012$).

Regarding the interview data, the following themes emerged from the analysis. One of the themes that emerged from the interviews was **real-life experiments** (**DR1**). This is also indicated by the significantly positive correlation between EVV and LOA. Several participants expressed the combination of technology and hands-on experimentation as positive and motivational, thereby a theme that evolved from the interview statements, as seen below. The fact that the app encourages the user to do something physical rather than passively looking at a screen was mentioned as a positive feature. When asked what the best part of the app was, one of the interviewees said, *"...It must be that it wasn't just looking down at a screen. It was something you could do, too, so it was good..."* Another participant also highlighted the same when asked why the participant would want to use the app: *"...I guess it was that I was at home with other people who tested the app, and we thought we could try it anyway because we had nothing to do but look at the phone..."* A third participant reflected upon the element of combining an app with hands-on experimenting when asked if they prefer for everything to be in-app rather than in real life: *"...This is an experimental game, so it's better to do it in real life than to do it on a screen. So I think it's good because you can use your iPad or screen for something other than just sitting and playing on it. In addition, you learn from it..."*

Another theme emerged from the questions regarding the **learning outcome of the app**. There were different perceptions of how much the participants had learned through the experiments. When asked if they had learned anything while using the app, a participant mentioned one of the experiments as useful: *"... Yes. We did the invisible writing in the experiments with lemon and stuff. So I feel like I learned a little bit in every experiment..."* Once again, we find that there is not only a correlation between EVV and LOA, but also the children indicate it. As another mentioned in one of the other experiments: *"...Yes, you kind of learn why it happens and stuff. That experiment with eggs, you kind of understand why they were so strong and things like that. Yes, so you learn things from it..."*

## 5.2 Design Requirements of Experiverse

When asking children what features they liked the best within the app, the experiment (**DR1**) and avatar (**DR2**) views were the most mentioned (we also observed that there is a significantly positive correlation between EVV and AVV). When asked about which views and gamification features motivated the children the most, one of them also drew attention to the battle pass view as one of their favourites: *"...I liked the avatar page, and I liked the page where one could browse through the planets. Where it says how much money or points you must have received to get to the next planet. I thought that page was cool..."* Our results on the correlation between EVV and BPV also indicate this relation. Children were also asked what they thought about the journey through the solar system in the app. One of them stated: "*...I also think it was pretty cool and creative because then it becomes more fun to do it so that something actually happens when you're done with the experiments. So that it's not just a text and then nothing happens. Yes, I thought it was cool...*" When being asked the same question, one of the other children added an idea of expanding the universe of the app: "*...It's a great way to get people to do experiments, and I think it was exciting. But it could have been the case that when you were done with the solar system, you switched to nature or something, that there are several orbits, that you get on to nature or the sea or something. Or you can travel in time and stuff...*"

When asked about design improvements to the app, one of the features mentioned was adding several different "worlds" to the gameplay. When finished with the solar system, the player would level up to a new game world with new challenges and experiments to solve (**DR4**). In addition, children's suggestions included letting people choose experiments more freely (**DR1**), adding missions to the app, and expanding the story of one being an astronaut or alien who fights against the other by doing missions and gathering points (**DR2**). Storytelling is an intriguing way for children to engage with the app, and a child can be featured as the main character of the story to make it more fascinating to them. The most mentioned aspects were game-based, including adding a battle pass, customising the avatar (**DR2**), and giving the users greater leeway in choosing which experiments they would like to do (**DR1**). The first participant was asked whether they would like more games in the app: *"...It would be nice to have some games you could get points in instead of just experiments. Like assignments, you can do. Then you might get 100 points instead of 250..."* They also suggested expanding the story with good versus evil gameplay: *"...Other missions and all that. Kind of like that; maybe you're going to try to get away from the astronaut if you're an alien. Also, you need to do missions to earn points. And maybe some game where you can shoot with spaceships at each other. That's a lot of good things. You can make aliens start from Neptune, the last planet, and the astronaut starts on Mercury to get to the sun and destroy it. The astronaut is going to destroy where alien lives in the Milky Way...."* One of the other participants expressed the wish for more customisation in the app, adding different age groups and experiments to match the target group: *"...If there were age groups, you could choose how old you were when you entered the app because some of them are easier than others. Maybe choose what experiments you can do on each planet."* A child pointed out that the fewer words, the better, and preferred a drag-and-drop interface where they did not have to write so much themselves*:"...I like when you have a lot of words, and you should find the right word. It would be nice if you didn't have to write so much but instead press around...."* One child also added that they would like the app to be adaptive so that the further the user got into the app, the more difficult it would be to move on. He also emphasised the importance of a battle pass, giving the user reward tiers (**DR4**) *"...Maybe if you'd done so that every time you came on a new planet, you'd need more points to move on. So you would have to do more experiments to move on. And maybe it could have been the case that you're levelling up. Do you know what a battle pass is? Because if you have a battle pass like that, with cool characters, and the app goes viral and does things and quizzes in the game and stuff like that, there are people who want to buy the battle pass and get other costumes and stuff. And if you have points so you can buy points to buy battle passes, you can make a lot of money..."*

# 6 DISCUSSION

This paper presents Experiverse, an experiment-based gamification application aiming to engage and motivate children to science learning in informal settings. One of the most important ideas behind Experiverse was that the children should use the app because they wanted to rather than because they felt they needed to, as [9] describe how the aspect of autonomy affects one's intrinsic motivation. It is interesting to note that the app's innovative part was also one of the parts that the children pointed out as the best thing about it. The interviews showed that combining technology and real-life experiments motivated the children to use the app. These findings show similarity to the results of the positive effects inquiry-based science learning has on children's motivation, where the child is engaged in their learning process [19].

Another interesting result from the interviews was that the children used the app when bored and wanted to do something other than just scroll on their phones. There was also suggested as an improvement that children should have more autonomy in choosing which experiment they would want to do on each of the planets in the solar system, rather than having a fixed list of three experiments on each planet. The fact that the results show that the children wanted more autonomy and more challenges in the app substantiates the SDT and the heuristics proposed by van Roy and Zaman, as seen in Table1. These results are also consistent with the findings of [31], which found that enhancing autonomy support in a system could increase children's intrinsic motivation.

Many learners struggle to link what is learned in the classroom with what is learned outside the classroom, as described by [14]. This suggests that children need support for transferring the knowledge they have learned between school education to learning environments. It may be possible that the children would have benefited more from using the app in a more controlled setting, for example, in a science class or activity, where they could have worked out hypotheses together. In case practitioners in structured activities look for more appealing resources to engage children in the science learning [33], the use of the app can be a way to engage them in these contexts. The findings of this study show that gamification can motivate children to learn science in an informal setting if there is a more apparent connection between the informal and formal learning processes. To understand how much the children have learned through the app, future research would be needed to examine it in a more prolonged and exhaustive study setting. The interview children in our study suggested adding quizzes to the app, writing the hypothesis before conducting the experiment, and then writing what happened afterwards.

We implemented gamification elements on Experiverse, such as a game storyline, avatars, progress, feedback, and points. Our findings suggested that children indeed perceive some elements as motivating. For example, besides the storyline and points, the avatar view (AVV) was one of the most influential in Experiverse and the feature that most children would like to have had more functionality. There is conformity on this point in both the interviews and the log data, which indicates that having an avatar in the application can be essential in motivating the children to use the application. However, even though the interviewed children expressed that the avatar was what they liked the best with Experiverse, they also wished for more customisation. The findings regarding the wish for customisation of the avatar also correspond with the heuristics constructed by van Roy and Zaman [30]. Making a system flexible by adding user characteristics aims to fulfil the basic psychological need for autonomy regarding being motivated.

The Battle Pass (BPV) was also a gamification feature mentioned as valuable in which the player saw their rewards as something to aim for. The possible rewards are listed in the battle pass, which can act as a motivating factor for completing experiments. It may be that the extrinsic motivation that points and rewards gave was greater than the intrinsic motivation to do experiments. The results indicate that battle passes and points in the app have increased the children's motivation, but maybe not necessarily the motivation to complete experiments to learn.

There is a significant positive correlation between the perceived learning outcome of the app (LOA) and the motivation (MO), which is in line with previous research [23]. Furthermore, when it comes to the storyline included in the app allows children to involve themselves in the application have the potential to motivate the children to use it again. These findings are comparable to the studies done by [13, 21] and indicate that even though points are seen as extrinsic motivators, they can also be seen as supportive elements which can facilitate learning.

There are some limitations to this study. The fact that the children should use the app at home was, on the one hand, important because the study was to test how children use a gamified app for learning outside of school. On the other hand, it posed a challenge because it is not possible to conclude that the facilitation of parents or teachers would have impacted the benefits of the app. However, previous studies by [7, 16] indicate that parental involvement could be beneficial in assisting children's problem-solving process. We noticed that it was difficult to anticipate school and parent restrictions which made the actual testing of the app difficult. In addition, the small sample size could be another limitation of this work. Another potential limitation of this study concerns the external validity of the results. Future efforts could focus on member checking with participants after the preliminary data analysis to further validate the results.

As future work, more research is needed to develop interactive apps for children to engage them in science learning. Aspects to be considered include the design elements of collaboration and interaction with peers to support social interactions; as van Roy and Zaman [30] pointed out, these systems should facilitate social interaction to fulfil the need for relatedness. In addition, offering customisation elements is a good way to fulfil children's needs.

## 7 CONCLUSION

This paper presents Experiverse, an experiment-based gamification application aiming to engage and motivate children to science learning in informal settings. Experiverse was developed and constructed based on six essential gamification design requirements, inspired by literature and insights gained from related works and expert interviews with elementary school teachers. To evaluate the children's experience with Experiverse, we involved 25 children for two weeks collecting data from multiple sources. Overall, this study's results are encouraging; this will suggest the potential of using gamification to promote informal science learning in children. The interview findings showed that combining technology and real-life experiments motivated the children to use the app. In addition, this paper reported that children's motivation (MO) significantly correlates with their enjoyment (PE) and perceived learning outcome from the Experiverse application (LOA). Our results also revealed a significant positive correlation between children's perceived learning outcome (LOA) and the number of Experiment view visits (EVV) on Experiverse. Last, this paper points out some implications for future related research; for instance, consider offering customisation elements in such gamification applications and facilitating social interactions and collaborations with peers.

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