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Bouquet, Elizabeth; von der Au, Simon; Schneegass, Christina; Alt, Florian

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CoAR-TV: Design and Evaluation of Asynchronous Collaboration in AR-Supported TV Experiences

Elizabeth Bouquet
e.bouquet@hff-muc.de
University of Television and Film Munich
Munich, Germany

Simon von der Au
s.vonderau@hff-muc.de
University of Television and Film Munich
Munich, Germany

Christina Schneegass
c.schneegass@tudelft.nl
TU Delft
Delft, Netherlands

Florian Alt
florian.alt@unibw.de
University of the Bundeswehr Munich
Munich, Germany

ABSTRACT

Television has long since been a uni-directional medium. However, when TV is used for educational purposes, like in edutainment shows, interactivity could enhance the learning benefit for the viewer. In recent years, AR has been increasingly explored in HCI research to enable interaction among viewers as well as viewers and hosts. Yet, how to implement this collaborative AR (CoAR) experience remains an open research question. This paper explores four approaches to asynchronous collaboration based on the Cognitive Apprenticeship Model: scaffolding, coaching, modeling, and collaborating. We developed a pilot show for a fictional edutainment series and evaluated the concept with two TV experts. In a wizard-of-oz study, we test our AR prototype with eight users and evaluate the perception of the four collaboration styles. The AR-enhanced edutainment concept was well-received by the participants, and the coaching collaboration style was perceived as favorable and could possibly be combined with the modeling style.

CCS CONCEPTS

• **Applied computing** → **Collaborative learning**; **Interactive learning environments**.

KEYWORDS

AR, interactive television, edutainment, mobile, collaboration

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1 INTRODUCTION

Asynchronous collaboration in augmented reality (AR) is still a scarcely researched topic. However, AR provides several benefits for collaborative work and learning. We investigated AR-supported asynchronous collaboration in the context of an edutainment show for children. Television (TV) is a passive learning medium, and its interactivity is limited by the fourth wall separating the learning audience from the person on the TV. Several edutainment shows have tried to break through this but have not overcome these limitations. AR can dissolve the fourth wall by enhancing the watching experience with interactive three-dimensional content and the opportunity to collaborate asynchronously with the people inside the TV.

In Germany, there is a high demand for skilled professionals in the STEM (Science, Technology, Engineering, Mathematics) field[1]. While the number of enrollments for STEM studies at German universities has increased over the last 15 years, there is stagnation since 2016. In addition, the proportion of female students enrolling in a STEM program has not changed and remains at only one-third of the total number of enrollments[2].

In STEM subjects, the students face various difficulties. These can be individual challenges like self-confidence, prior knowledge, or personal learning style and motivation. Problems can also be STEM-specific due to the abstract and complex nature of the taught concepts or their application relevance to real-world problems. Also, socio-cultural challenges can play a role, like the qualification of the teachers, access to certain learning resources, or gender stereotypes.

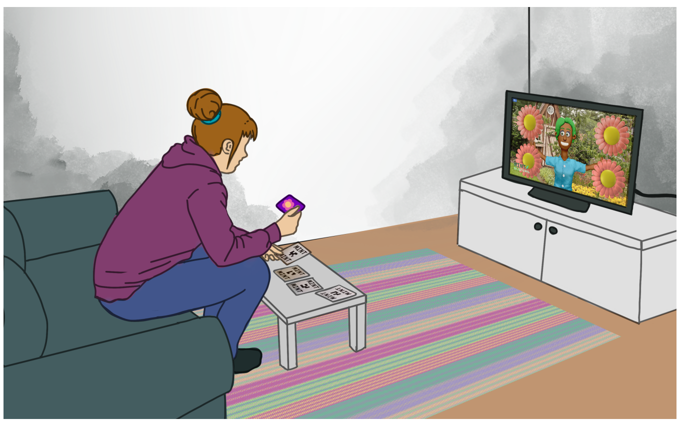
These circumstances motivated us to design a TV show format as a use case for our user study that addresses (mainly female) children and teenagers and aims to create an interactive and collaborative learning environment, including the leaned-back learning medium television and the advantages of AR technology.

Considering existing research on AR-enhanced collaboration, learning theories, and edutainment we developed a show concept that combines an edutainment TV show format with interactive features and collaboration via augmented reality to get young people, especially girls, into STEM topics in a playful way. We evaluated the concept by discussing it with professionals in the TV industry.

[1] https://de.statista.com/statistik/daten/studie/420127/umfrage/mint-berufe-offene-stellen-in-deutschland-nach-bundeslaendern-und-berufsaggreggaten/
[2] https://de.statista.com/statistik/daten/studie/1050875/umfrage/studierende-in-mint-faechern-in-deutschland-nach-geschlecht/

In a user study (N=8), we investigated four collaboration techniques demonstrated with a Wizard-of-Oz prototype. To investigate collaboration between the audience and a show host, we derived four types of collaboration techniques based on the Cognitive Apprenticeship Model [7] that differ in their extent of support of the viewer from the show host's perspective - ranging from only providing a proper learning environment over modeling the solution and giving active feedback to an active supporter role.

In summary, we discovered that experts and participants verified our overall concept. Furthermore, using the Cognitive Apprenticeship Model [7] as a template for asynchronous collaboration techniques was successful and led to the following results: The show host reacting with feedback and modeling a similar solution before the learner starts were the most appreciated types of collaboration. Therefore, we recommend an adaptive collaboration composed of both approaches and based on the learner's needs for upcoming CoAR-TV learning experiences.



(a) In our CoAR prototype, users collaborated with a virtual TV show host using a smartphone-based augmented reality application and physical image trackers.

(b) The show host *Minty*, which was animated using Adobe Character Animator, welcomes the viewers and introduces the episode's topic.

Figure 1: "MINT Busters" is an AR-supported collaborative and interactive edutainment format for children (10–14 years), explaining STEM topics playfully and interactively.

2 BACKGROUND AND RELATED WORK

Our work on CoAR-TV is located at the intersection of three research fields: Collaboration in AR, AR-supported learning, and edutainment. We provide a brief overview of related work and theories in these fields and identify research gaps.

2.1 Augmented Reality for Learning

AR offers many opportunities to support learning according to the constructivist paradigm. Based on constructivism, knowledge is repeatedly constructed, reorganized, and expanded by the learners individually, while the teacher takes on the role of a moderator [16, 60, 61]. In line with that, AR applications can be used to build and create their own experiences, learning environments, or even code [14, 29, 54]. Furthermore, interactive compilation of content makes it possible to provide learners with individualized feedback and offer targeted support. There are multiple research projects where AR is used for different purposes to support learning:

One key value of AR in education is visualizing objects or concepts that are not visible with the bare eye or too big or too exotic to bring into the classroom [1, 8, 47]. Especially STEM lessons can benefit if abstract concepts can be made visible and interactive [32, 59]. Those AR applications are often combined with visual markers or extend the content in books to provide a further medial layer [12, 22, 33, 53]. For example, Botella et al. [7] enhance the periodic table with an AR overlay to visualize the atoms in three dimensions. They can also provide representations and further information about the described molecules based on text recognition. Taking this concept further, some projects augment real objects to enhance them with further information or visualize invisible chemical processes [11, 25, 37].

Another type of project leverages the real-time possibilities of AR to provide instructions and direct feedback. In particular, in biology, physics, and chemistry, students benefit from manipulating conditions and seeing the direct results [20]. Some projects use a virtual assistant or teacher for explanations based on the individual learner's state [45, 63]. Besides STEM, these concepts can also be used for music [9] or language [13] education. Another advantage of AR in learning is the possibility to integrate body-based metaphors [28, 38, 42], which positively affect learning success [10].

2.2 Collaborative Learning

The positive effects of collaboration and cooperation are well known for teaching [21]. Herrington and Herrington [17] describe the collaborative development and reflection of knowledge as essential criteria for creating an authentic learning environment. Furthermore, Herrington [18] and Reeves et al. [46] describe authentic learning environments in interactive multimedia spaces and for online learning. They identify collaboration as a key to successful and joyful learning and one main advantages of such environments.

2.2.1 AR Supported Collaborative Learning. Phon et al. [41] reviewed the existing literature exploring the interface between collaborative learning and (collaborative) AR applications. The conclusion was that the unique combination of real and virtual objects can help learners improve their problem-solving skills and communication when completing group tasks. The 3D perspective also helps grasp complex concepts and even visualize concepts that cannot be represented in the real world (e.g., molecules) [43, 44]. The playful nature of AR and the visualizations lead to greater learning comprehension, higher satisfaction, more motivation, and better focus when learning [15]. Most examples in this area enable synchronous collaboration between users in a shared location with feedback based on interaction from the system [19, 27, 30, 64]. Through AR, two or more learners share an experience. Therefore, they can solve problems together. Blueprint for a lot of research in STEM education are the projects "Studierstube" [24] and "PhysicsPlayground" (2008) [23]. To further support the collaboration between learners, Villanueva et al. [57, 58] added AR annotations to their experience, enabling asynchronous collaboration.

A few examples support a synchronous but remote collaboration between users and can best be described as social learning environments that are enhanced with AR [40, 65].

2.3 ARTV: Augmented Reality and Television

Augmented Reality is becoming more accessible to the public, and its applications in domestic environments are growing. Saeghe et al. [49] saw the potential to use it with an already adopted technology at home: The television. By reviewing previous research on the intersection of AR and TV that is focused on visual-only aspects of AR, they identified six different themes: AR was used to augment the TV-watching experience in the living room (1), in the context of production (e.g. in virtual studios) (2), for alternative experiences outside of the living room (3), to connect remote audiences (4), for live-video augmentation (5), as well as for photogrammetry (6). Saeghe et al. developed a six-dimensional design space for ARTV applications. Abstraction (1) describes the relationship between AR and TV content and their dependence on each other. Interaction (2) defines on three gradations how much influence the viewer has on the experience when interacting with the AR content, from only switching between different view modes ("display level") over driving the storyline ("structure-level") to manipulating the content of a broadcasting show ("content-level"). While the aspect Time (3) represents the temporal relation between AR and TV content, the Display (4) specifies how the respective contents are displayed to the viewer (e.g., same device vs. separate devices), and Context (5) includes the whole context of the application (e.g., the audience and the location). The sixth aspect, Editorial Control (6), describes if and how specific editorial decisions are given to the audience, like camera angles and shots.

Vatavu et al. [56] introduce a two-dimensional ARTV-Continuum, combining Milgram et al.'s Reality-Virtuality-Continuum [35, 36] with Schraffenberg's categorization of AR applications [50] based on a systematic literature review. It is focused on the viewer's perspective and does not differentiate between AR display types. The resulting ARTV framework provides an overview of how different degrees of virtuality of TV content and environment can be combined to inspire diverse creative ARTV applications. Based on their results, they suggest various scenarios of how AR can enhance a TV experience: Virtual elements in AR with additional information (1), multiple virtual screens in addition to the TV screen (2), expanding the field of view around the TV device (3), and asynchronous content that could provide the audience additional content (4).

2.4 Edutainment

Brown et al. [7] postulated that knowledge is best acquired in the context in which it is later applied. Nevertheless, learning frequently occurs in abstract and detached settings, such as classrooms, far away from the actual field of application. Media-supported learning has the potential to establish authentic environments to support such situated knowledge construction. One common way to create such a context in, e.g., classrooms is using audiovisual media.

E-Learning, T-Learning, or Edutainment can support an authentic learning experience by creating relevance to learners [39]. Furthermore, edutainment (educational entertainment) content is designed to be entertaining, engaging, and can support long-term learning [55]. The transition between edutainment (or t-learning) and web-based learning (or e-learning) is fluent [39].

2.4.1 AR Supported Collaborative Learning in TV Setups. A way to enhance edutainment with interactive elements is by adding AR. Thus, the TV content can be expanded in three dimensions, and additional content concerning the show can be displayed in the learner's environment. This provides the opportunity to engage with the TV content, use different perspectives, or build deeper knowledge. For example, von der Au et al. [62] provided the 3D assets used to produce the edutainment show also for an additional AR app to view the AR content in combination with the show. Besides offering additional content, there are a few examples of AR enabling collaboration in learning experiences. Ballagas et al. [2] and Revelle et al. [48] present an interactive AR-supported edutainment show for children to support language learning. The show is designed so that through AR, on the one hand, two learners can collaborate in the same location, solving puzzles together. On the other hand, the learners can collaborate with the show hosts through AR. Based on the solutions the learners present for the puzzles, they get individual feedback from the hosts. This is possible through many prerecorded video pieces, composed in real-time, to provide helpful feedback or congratulate the learners on a successful solution. Lorusso et al. [31] use a similar concept. A group of learners is enabled through an augmented tangible user interface to alter the story presented on a TV. Thus, young children can interact with the animated character and solve quizzes as a group.

2.5 Summary and Research Gap

In summary, a solid body of work already underlines the assumption that AR offers many benefits for learning and collaboration. Especially in STEM education, collaborative learning and experimenting are fundamental learning methods. AR can support collaboration in a very natural way and can provide useful visualizations to assist the learners. While TV experiences can benefit from additional AR content, edutainment formats could also benefit from these features and integrate interactivity and collaboration into their content. However, nobody examined what collaboration styles benefit users in an AR-enhanced collaborative edutainment show. Asynchronous remote collaboration is still a niche in research [34, 51]. In the context of broadcasted edutainment content, it is challenging to implement synchronous collaboration between one moderator and a diverse audience distributed over multiple living rooms with currently available technologies. We see great potential in asynchronous collaboration for a collaborative learning experience between the pre-recorded show moderator of an edutainment format and its learner audience. Plus, augmented reality provides promising features for implementing an interactive ARTV application that also serves as an effective learning environment.

The following sections will describe our research approach and concept of an AR-supported edutainment format. After illustrating our prototype and the study design and procedure, we present and discuss the user study results.

3 RESEARCH APPROACH

Our approach can be structured in three phases: The design phase, the prototyping phase, and the evaluation phase.

In the *design phase*, we examined different edutainment shows from the past, including German educational shows for children and interactive educational formats. We discovered different approaches of these shows to teaching technology and science topics and summarized the educational and gamified principles they took advantage of. Based on these already successful edutainment shows, we developed our own concept for an AR-supported interactive edutainment show for children and teenagers and presented it to two film industry experts to gain their feedback before prototyping.

In the *prototyping phase*, we focused on the collaboration techniques we derived from Brown et al.'s Cognitive Apprenticeship Model. We developed a Wizard-of-Oz prototype for a possible pilot episode of our edutainment show based on digitally prepared video sequences and a mobile AR application to let our study participants experience the concept as realistically as possible.

In the *evaluation phase*, we evaluated four different collaboration techniques with eight participants in a within-subject study. To measure and compare them, we used usability questionnaires to let the participants rate their experience with the different collaboration modes with the show host. In addition, we conducted a semi-structured interview to gain further insights into the reception of combining a television program with augmented reality content.

4 SHOW CONCEPT: MINT BUSTERS

The following section will present our AR-supported edutainment show concept and its socio-cultural motivation. Before developing our own concept, we investigated and compared different German edutainment shows and international interactive edutainment formats to gain insights into their approaches to using television as a learning medium. Furthermore, we presented our concept to two film industry experts who gave us rich feedback.

4.1 Design Principles in Edutainment Formats

To learn more about the production of edutainment formats for children and teenagers, we investigated several edutainment shows from the past, including German edutainment shows for children and international interactive edutainment formats. We discovered that there were four educational principles that they had in common: (1) They used analogies to provide a more understandable description of complex topics, (2) they illustrated abstract concepts with the help of anthropomorphic visualizations, (3) they tried to establish a parasocial relationship to their viewers by talking directly to the camera, and (4) they presented easy to follow instructions for experiments that the children could do on their own at home with housewares. In addition, even though they had different approaches, there were edutainment shows that integrated gamification principles into their program to let viewers be active in the show. Some used interactive storytelling where the viewers could choose what the main character does next. "Winky Dink and You"[3] integrated creative drawing with a pen and a plastic sheet where the viewers could extend visuals on the TV with their own drawings. "Electric Company"[4] included telephone calls to let viewers talk to the show hosts and contribute to the show's topics. The German science edutainment format "Princess of Science"[5] regularly invited children to join their episodes and investigate certain STEM concepts with experiments playfully. Every guest got a place on their "wall of fame" with a picture of them and a paper crown on their head.

4.2 Description of Concept

Our concept is based on the idea of an interactive AR-enhanced TV show for children that teaches them STEM topics in a clear and graphic way and allows them to discover the concepts in a playful manner. We called the show "MINT Busters" which is a wordplay that refers to the German equivalent of the acronym "STEM" and the documentary show "MythBusters"[6] where the show hosts were regularly challenging urban myths with experiments.

The show format is supposed to be episodical and consists of episodes covering different STEM-specific topics driven by a background story that connects the topics with real-life problems. The episodes' stories can but do not have to relate to each other. Each episode is split into a storytelling part that explains the theory and an interactive part that transfers the theory knowledge into a hands-on experiment with a problem-solving challenge.

While TV is used to provide the main story of the show and the explanations, AR is the medium to enable interactivity and collaboration in the TV show as it can visualize 3D data, make invisible things visible, has a playful and novel character, provides a safe environment, and does not require additional material or tools.

A first season could include eight episodes with the following topics: (1) number ranges, (2) hydrological cycle, (3) statics & bridge construction, (4) electrical circuits, (5) logic & logical circuits, (6) programming, (7) acids & bases, and (8) gravity & space-time.

The show is moderated by a female character with an approachable nature called "Minty". She guides her audience through the show's story and explains the STEM theories with the help of visualizations and analogies. During interactive parts of the show, she supports the viewers with hints, feedback, and collaboration. We decided to have a female person of color as a show host to open up to a more diverse young audience after we discovered that in the past of children's edutainment formats, the moderators were mostly male. Minty should be a young adult representing a big sister that the younger audience can relate to and learn from. We styled her with a green and short haircut to give her a queer visual appearance.

Advanced Concepts: We also discussed some advanced concepts we did not implement in our prototype.

[3]https://www.imdb.com/title/tt0045456/
[4]https://www.imdb.com/title/tt0066651/
[5]https://www.zdf.de/kinder/princess-of-science
[6]https://www.imdb.com/title/tt0383126/

The fourth wall that separates the living room and the showroom could be dissolved further by letting the show take place in the living room or by letting the host walk into and out of the living room. Furthermore, the experiment results of the children could visually become part of the show, e.g., a bridge that a viewer built as an experiment is afterward part of a scene where the show host is crossing a river by walking on this exact bridge.

To offer the children an incentive to keep watching the show and being active participants in the episodes' challenges, we thought of the concept of collectibles called "MINT drops". After completing an episode and solving the challenge correctly, the children could collect a certain amount of these drops. These drops could then be used to exchange them for additional content, which could be content to personalize the TV show. This could include the whole appearance and character of the show host, the showroom's furniture, and additional story content.

We also wanted to revive the concept of a live game show for children where the guests worked in teams to win challenges. Such a format could also benefit from the advantages of augmented reality. MINT Busters could provide such a format every two months and invite children from their audience based on their commitment to the regular show's challenges. The show should also provide a stage for special guests from STEM industries presenting their profession, working life, and career path to give the children firsthand insights on possible future job decisions.

4.3 Expert Evaluation

We presented the show concept to two TV and film industry experts and discussed it with them in two sessions. Both were convinced of the overall concept of the AR-enhanced edutainment show. They see great potential for kids in this age group with new tech-supported interactivity and a "cool" show host leading the viewers through the world of STEM concepts, like a hero figure. Personalizing the content could work well for 10–14-year-old kids.

For the general design of the show host, the second expert suggested more investigations on what the target audiences consider "cool" and "appealing". Currently, upcoming trends, like TikTok dances, Pokémon, and Fortnite, could make up a great source of inspiration. Furthermore, combining the TV experience with AR interactions "is innovative" and could work well for children due to the higher interactivity.

The first expert stated that shooting a season of this concept consisting of 14 episodes with an interdisciplinary team of designers, software engineers, and editors could be imaginable. The second expert found the concept more suitable for streaming services or video education in school, as it "feels a bit too forced into the broadcasting format". This could produce time pressure, leading to a more stressful experience for more slow-paced learning types.

Using a mobile device as an AR enabler would make this edutainment format accessible to more children, as smartphones and tablets are more common in today's households than AR-HMDs (Head-Mounted Displays), according to the second expert. They also recommended using finger tracking or similar interaction techniques to eliminate any additional material (like paper cards) so that the viewers could join the educational experience even faster by just using the TV and their mobile devices.

The first discussion ended with a deep dive into the subject of face and body tracking and how a virtual character can be animated with current software products and a simple webcam (like Adobe Character Animator) or with the newest technological devices (like Quest Pro) that are already able to operate without any additional markers. If the technical possibilities for tracking work "as easily and effortlessly as it seems" then they could indeed "envision using such a technology for live broadcasting the presented concept."

5 COLLABORATION EVALUATION

5.1 Research Questions

Our main research question was defined as follows:

RQ How can AR enhance the interaction and collaboration of an edutainment TV show for children?

We subdivided this question into three aspects: interaction via AR, collaboration via AR, and the effects of interactivity and collaboration on the TV experience. This led to three questions:

RQ1 How can a viewer interact with the moderator using AR?
RQ2 How can viewers and hosts work collaboratively on a task using AR?
RQ3 How can the result of the collaboration affect the TV experience?

5.2 Use Case

As a use case for our study, we produced a pilot episode for our TV show "MINT Busters" covering the mathematical concept of natural numbers N, integers Z, and rational numbers Q. The pilot episode is structured as follows:

After an introductory sequence showing STEM-related clips accompanied by uplifting music and closing with the appearance of the logo of MINT Busters, the show host Minty welcomes the viewers to the new episode of MINT Busters. She leads the episode's topic by talking about the upcoming spring season and a number flower garden. Then, she dives into the concept of natural numbers, integers, and rational numbers by explaining why they exist, what they look like, and how they are related, supported by visuals.

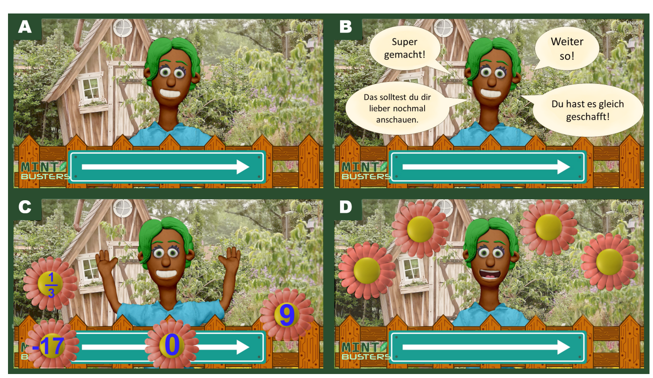


Figure 2: The four different collaboration variants of the show host *Minty*, (A) Scaffolding, (B) Coaching, (C) Modelling, and (D) Collaborating.

After explaining the concepts, the episode transitions to the first task, which will be part of the interactive section of the episode, by asking for help with planting flowers. Minty hints that the viewer has to use their smartphone to join the interactive part. Furthermore, she guides how to plant the number flowers correctly: The numbers displayed on them must be put in ascending order along the number line visualized on a fence in the TV show. The viewer solves the mathematical problem using the AR application and the paper trackers. Afterward, they get feedback on their performance.

After accomplishing the whole section, the show host acknowledged their help by showing the blooming flower garden the viewers created and saying goodbye. The episode ends with an outro, showing the intro clip in a minimized window and rolling "dummy" credits accompanied by the same uplifting music as the intro.

5.3 Study Design

We conducted a within-subject study to investigate the effects of different collaboration styles of the moderator with the test viewer. We recruited a group of participants (N=8; 50% identifying as female, 50% identifying as male) aged between 28 and 31 years to test all four different types of collaboration with the show host. We decided to invite young adults because they were also children not so long ago, and they could give us more profound feedback on their experience with the prototype.

The four collaboration styles we compared in our user study (see also Figure 2) are based on the theory of "Cognitive Apprenticeship" [7] and are defined as follows:

A Scaffolding: The least collaborative style. The host explains the task and offers an environment where the viewer can solve the task (a number line in this case).
B Coaching: The host explains the task and gives immediate verbal feedback to each step the viewer takes to solve the problem, giving hints if they are on the right or wrong track.
C Modelling: The host demonstrates how the task can be solved step by step with a different example before the viewer can engage in their own task.
D Collaborating: The viewer and the host work together on the same task and take turns.

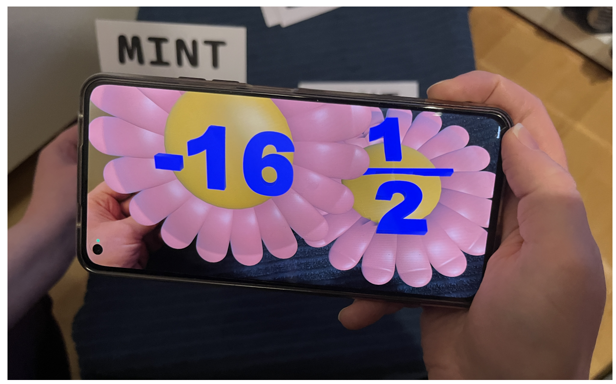
To decrease carryover effects, the condition order was counterbalanced with a 4×4 Latin square design. Furthermore, we changed the numbers that had to be sorted in ascending order in every condition to decrease boredom and learning effects. The numbers were taken randomly from the set S = [-16; -4; -1/78; 1/2; 1/32; 5; 53].

We used several methods to collect qualitative data from the participants. Besides measuring our concept's usability and user experience using the SUS and UEQ-S, we collected information about the participants' demographics, school experience, TV consumer behavior (as a child and today), and their experiences with AR technologies. In addition, we discussed the overall concept within the scope of a semi-structured interview, including eight questions.

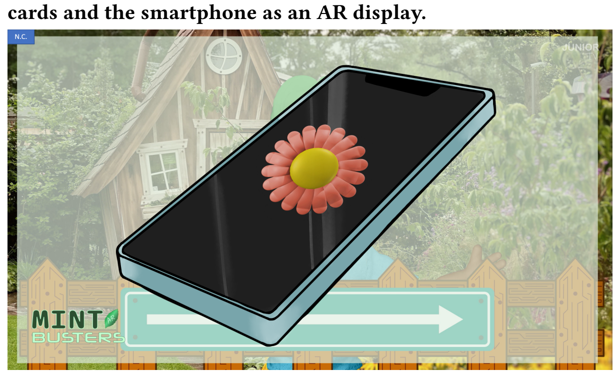
5.4 Apparatus

We built a *Wizard-of-Oz prototype* [4] by combining already working and mocked features. On the one hand, we implemented a working AR mobile application and produced several prototype show sequences. On the other hand, we mocked the interaction between the AR application and the TV show, as well as the show's broadcasting. With that approach, we could quickly evaluate the overall concept and the interaction with AR and TV content before jumping deeper into concept development.

The *mocked TV show* sequences were produced with Adobe AfterEffects[7] in MP4-format using custom footage and stock footage from pixabay.com[8] (Creative Commons Licence). The host character called "Minty" was created and animated using Adobe Character Animator[9] and a customized clay figure puppet. The character was voiced by one of the authors whose voice was altered with the help of the voice modulator Voice.AI[10]. To mock broadcasting on TV, the show sequences were presented on a TV with a notebook using PowerPoint[11] and a remote presenter device to give the participants the illusion of an interactive, broadcasted TV experience.



(a) The AR mobile prototype of "MINT Busters" works with image tracking where the viewers interact with physical paper cards and the smartphone as an AR display.



(b) The show host *Minty* asks the viewer to grab their smartphone for the following interactive part of the "MINT Busters" episode.

Figure 3: The pilot episode of "MINT Busters" includes a mobile AR application to provide the viewers with interactive and collaborative features.

[7] https://www.adobe.com/de/products/aftereffects.html
[8] https://pixabay.de/
[9] https://www.adobe.com/de/products/character-animator.html
[10] https://voice.ai/
[11] https://www.microsoft.com/de-de/microsoft-365/powerpoint

The *AR app* was implemented with Unity[12] and ARFoundation[13]. It includes self-made 3D models of flowers displaying numbers (created with Blender[14]) and an image tracking functionality that renders the 3D models on top of physical tracker cards made of paper (image size: 600 px × 600 px; printed size: 12.7 cm × 12.7 cm – recommended by ARCore[15]). The app was deployed to an Android phone (see Figure 3a and Table 1 for specifications). With that app, the participants could see the virtual flower objects through the phone while interacting with them by moving the physical cards.

To make the whole TV-watching experience as immersive as possible, we prepared a lab setup that looks and feels like a living room. The room included a sofa, a small table, and a TV mounted on a TV board. Next to this living room setup was a desk with a laptop used for the interview recordings and two chairs.

Table 1: Specifications of all devices used in the user study.

Device	Model	Specifications
Television	Philips SQ522	37" (58.5 cm × 50.0 cm)
Smartphone	Xiaomi 11lite 5G	160.53 mm × 75.73 mm, 158 g
Presenter	Logitech R400	-
Notebook	Gigabyte G5MD	-

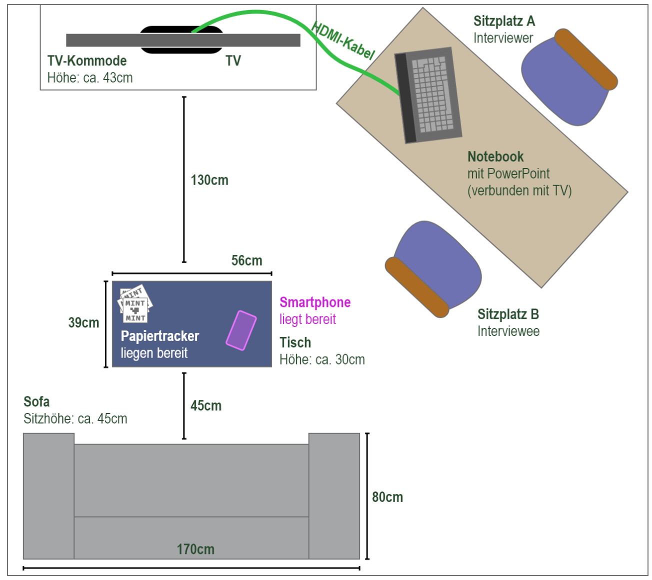


Figure 4: Setup of the MINT Busters Wizard-of-Oz prototype.

5.5 Procedure

The study was structured in three parts: A warm-up, the main study, and a semi-structured interview.

The participants had to complete a questionnaire in the *warm-up part*. Besides their demographics, we wanted to gain insights about their school life, their relationship to television, and their experience with AR technologies. To get to know their school life, we asked them questions about their most and least favorite subjects. Furthermore, we wanted to know which subjects were interesting to them but were too hard to learn and why. Our goals were to find out which subjects, in particular, were challenging for them to get into and which circumstances prevented them from understanding these subjects. Aside from that, we wanted to investigate their personal TV consumerism. They had to state how often they used to watch TV as a child and how often they watch it currently in their everyday life. Then, they were asked if they consumed (German) edutainment content and which edutainment show they watched specifically. The questionnaire concluded with questions about their experience with AR technologies and how they would imagine a combination of AR technologies with TV content. Then, the participants got a brief explanation of the procedure without mentioning the mocked connection between the TV content and the AR application. Before starting the study, they were introduced to the AR app to try it out beforehand and get used to it.

During the *main study*, the participants sat on the sofa and started watching the MINT Busters episode. While watching the explanatory part of the show, they leaned back and got into "watching mode". After the show host explained how to use the mobile phone to participate in the following interactive session, they leaned forward and grabbed the smartphone on the table before them (see Figure 1a). During the interactive part, they did the same task of sorting numbers four times in a row, but the show host collaborated differently with them each time, and the numbers changed. After passing the task, the show was "rewound" to the end of the explanatory part. After passing it the fourth time, the participants watched the end sequence of the show and the closing credits.

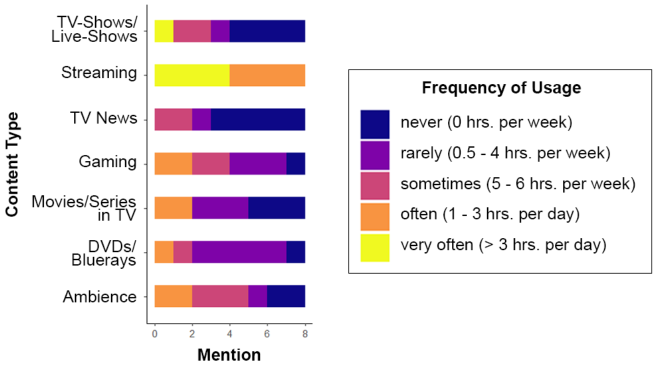
The *semi-structured interview* was held at the desk next to the living room setup and was audio-recorded after the participants signed a data processing consent. They were asked seven questions about the overall concept of MINT Busters, the combination of the two media channels, TV and AR, and the collaboration with the show moderator. After the interview, they were thanked for participating in the study, and if they were interested, they got a brief behind-the-scenes look at the preparation of the show sequences.

[12]https://unity.com/de
[13]https://unity.com/de/unity/features/arfoundation
[14]https://www.blender.org/
[15]https://developers.google.com/ar/develop/augmented-images?hl=de

5.6 Results

We present and discuss the results of our pre-study questionnaire, the main study form, and the semi-structured interview directly after the main study. The pre-study questionnaire was filled out once by each participant, while the main study form – including four different measurements – was filled out after each of the four test conditions that were introduced in Section 5.3. After the main study, we interviewed the participants and audio-recorded the sessions.

5.6.1 Questionnaire. We asked some questions about the participants' school life. We wanted to know which subjects they liked the most or the least. In addition, they should pick subjects that they found interesting but hard to learn and specify why they experienced difficulties while learning them.



(a) Participants use their television device mainly for streaming services, ambiance, and gaming – rarely for broadcasted content.

(b) Participants judged the concept of an interactive edutainment show for children by combining a TV show with an AR app.

Figure 5: The pilot episode of "MINT Busters" includes a mobile AR application to provide the viewers with interactive and collaborative features.

As *most favorite subjects*, the participants stated English[16] (6/8), Art (5/8), German[17], Geography, and Music (each: 3/8). The participants' *least favorite subjects* in school were Economy and Law (5/8), Social Studies, Mathematics (each: 4/8), Chemistry (3/8), Physics, Informatics (each: 2/8), and Biology (1/8).

The most mentioned school subjects in the category "*interesting but difficult to learn*" were Physics (6/8), Mathematics, Informatics (each: 3/8), and Chemistry (2/8). The reasons participants stated they had difficulties learning these subjects were diverse. Their "interest wasn't sparked" or their "disinterest raised with continuously bad performance [in tests]". While one explanation was that "sciences were too abstract [for them] to be easily grasped," there was one participant that "was sure that it wouldn't be possible for [them] to understand [...]". Also, on the one hand, they blamed their own "procrastination" or "laziness"; on the other hand, they accused the teachers of being "difficult" and felt a "high pressure to perform". The "high teaching pace" and the "low learning pace" did not match well; for some, personal hurdles (e.g., dyslexia) came on top. Furthermore, they often missed a "connection to diverse applications in everyday life".

[16]English taught as foreign language
[17]German taught as first language

These statements show which problems students already had around 15 years ago, also with STEM-related teaching content. Different personal prerequisites (knowledge level, learning speed, impairments) combined with the daily routine in school that seems perceived as stressful, overwhelming, and demotivating could lead to a loss of interest and motivation among students. And in the worst case, they don't feel competent enough before even trying (like one of the participants shared with us).

Next, we gathered insights into participants' TV consumption today and in the past as a child. We asked them to rate their consumption on a 5-point Likert scale from "never" to "very often". Today, most participants (7/8) watch TV "often" or "very often"[18]. In the past, they watched less, but half of the participants indicated having watched TV "often" or "very often". In addition, they were asked to specify what kind of content they consume today via their TV device constrained with the seven predefined categories: TV shows/live shows, TV news, TV movies/series, DVDs/Blu-rays, game consoles, streaming services, and ambiance (e.g., listening to music). All participants use their TV devices for streaming services "often" or "very often". Half of them never watch TV shows/live shows or news. Some use it for ambiance or gaming, and the minority watches TV shows or broadcasted movies/series (see also figure 5a). This indicates a slight shift from broadcasted content to self-determined content.

We also asked for *edutainment shows*[19] that they watched regularly in the past as children. The most mentioned shows were "Die Sendung mit der Maus"[20] (4/8), "Löwenzahn"[21] (4/8), "Wissen macht Ah!"[22], and "Galileo"[23] (both 3/8).

The last section of our questionnaire contained four questions related to *AR and ARTV*. 75% of the participants could imagine using AR in their everyday lives (very) well, and 25% could partially imagine it. 77.5% could envision using an AR application combined with a TV show, while the rest could partly imagine this usage. 75% could picture themselves as a child who would have enjoyed AR applications, like games, and 25%

As a last question, we asked participants to envision a concept that introduces interactive content via an AR application to an episode of an edutainment show for children and to judge it. Therefore, we provided a short version of the product reaction cards by Microsoft[3] containing 25 adjectives, and every participant could choose four of them to describe their vision of this concept. The most frequently mentioned adjectives included "innovative", "entertaining", "exciting", and "inviting". There were also some rather negatively connoted words such as "intimidating, "complex", and "overwhelming". Several mentions of the terms "helpful" and "collaborative" showed us that our concept could meet some of the expectations of our participants (see Figure 5b).

5.6.2 Measuring the Collaboration Style. To compare the four different collaboration styles in our main study, we chose the two questionnaires System-Usability-Scale [5] (SUS) and User Experience Questionnaire [26] (UEQ-S) to measure the perceived usability

[18] "very often" was defined as "more than 3 hours daily", "often" as "1-3 hours daily"
[19]The question included only edutainment shows that aired in German broadcasting.
[20]https://www.wdrmaus.de
[21]https://www.kika.de/loewenzahn/loewenzahn-114
[22]https://kinder.wdr.de/tv/wissen-macht-ah/index.html
[23]https://www.prosieben.de/serien/galileo

and user experience of our Wizard-of-Oz prototype. In addition, we asked the participants to rate the overall interaction with a given Likert scale and three self-formulated adjectives to gain more insights into their impressions of the concept. The participants were asked to complete a form after each condition, including all the mentioned measurements.

System Usability Scale (SUS). The SUS [5] is a questionnaire consisting of ten five-point Likert scales that include questions about how easy a system is to use and if the participants would use the system again[24]. To compare the four conditions, we calculated the mean, the standard deviation, and the standard error. The calculation of the mean resulted in the average SUS scores of

$\overline{x}_A = 89.06$, $\overline{x}_B = 92.5$, $\overline{x}_C = 93.75$ and $\overline{x}_D = 92.5$.

While all four values are above average (68), condition A–*Scaffolding* scored slightly lower than the others. These results show that the demonstrated collaboration concepts were perceived well and that our mocked system is easy to understand and use.

User Experience Questionnaire (UEQ-S). We use the short version of the UEQ[25]. Condition A has the lowest values for both qualities ($Prag(A) = 0.281; Hed(A) = 0.625$), but both values are still in the neutral range of the UEQ scale. Condition D got the highest values of all conditions ($Prag(D) = 0.844; Hed(D) = 0.781$) and is the only variant with a pragmatic quality over 0.8. The conditions B ($Prag(B) = 0.625; Hed(B) = 0.75$) and C ($Prag(C) = 0.375; Hed(C) = 0.719$) lie in between the other two conditions' values. The pragmatic quality of B is significantly higher than C's, and its hedonistic quality is a bit higher than the value of C. It also stands out that the hedonistic quality of variants A, B, and C is better than their pragmatic quality, while the pragmatic quality of D is higher than its hedonistic quality (see Table 2).

Likert-Scale of Interactivity and Behavior Rating by Adjectives: Next, we measured the interactivity of the show host "Minty" by asking for a validation based on a five-point Likert-scale (1 = "very bad", 5 = "very good") [6] and by requesting three self-formulated adjectives describing *Minty*'s behavior from our participants. The Likert scale shows a significant difference between condition A - *Scaffolding* and the others. Condition A got the lowest value, and conditions B, C, and D all have a 75%-rate of "very good".

During evaluating the self-formulated adjectives, we consolidated terms with similar meanings, e.g., "helpful" and "helping".

Table 2: Results of the UEQ-S questionnaire: The pragmatic and hedonistic quality of the examined collaboration styles (A) Scaffolding, (B) Coaching, (C) Modelling, (D) Collaborating (positive values above 0.8, neutral values between -0.8 and 0.8 and negative values below -0.8).

	Collaboration Styles			
Quality	**A**	**B**	**C**	**D**
Pragmatic	0.281	0.625	0.375	0.844
Hedonistic	0.625	0.750	0.719	0.781
Overall	0.453	0.688	0.547	0.813

All conditions contained the term "friendly" or comparable descriptions, which picture the overall appearance and character of *Minty*.

The minimal interactivity of *Minty* in condition A–*Scaffolding* was described as "friendly", "neutral", "inviting" on the one hand and "static", "calm", "absent" on the other hand. The more neutral and not very interactive show host was experienced as such but wasn't perceived negatively.

In condition B–*Coaching*, the show host behaved more interactively by giving verbal feedback to the user inputs. The behavior was described as "friendly", "motivating", and "supporting". The positive feedback was perceived as "demanding", "brightening", "praising", and "rewarding", which leads to the assumption that this behavior positively affected their motivation and confidence.

Condition C–*Modeling* involved a variation of *Minty* to demonstrate a possible approach to the task with a different set of numbers before letting the participants solve their task independently. She was described as "friendly", "supporting", "motivating", and "helpful", which shows that the participants found the step-by-step demonstration helpful. She seems more experienced in the teacher role because of the further provided adjectives "leading" and "teacher-like". Furthermore, the participants perceived her as "interactive" and "cooperative."

The most collaborative condition D–*Collaborating* led to mixed perceptions. While described as "friendly", "helpful" and "supporting", *Minty* was also experienced as "intervening".

In summary, the interactivity of the show host was perceived positively, and her character as a helping, supporting, and collaborating partner and, accordingly, as a motivating and encouraging personality that stays and reacts to the users with active feedback.

General Observations during the Main Study: During the main study, it was interesting to observe participants' reactions to the interactive behavior of the TV show. After introducing the interactive task and before it started, *Minty* prompted the viewers to grab their smartphones ("explorer glasses") by showing a smartphone picture and audible instruction. Five of our eight participants reacted immediately by picking up the smartphone in front of them. One participant didn't react immediately and needed a second hint to reach for the phone. The other two participants were unsure and asked if they could pick up the phone.

The diverse reactions to the feedback were also interesting because two participants were surprised by the reaction of *Minty* on their input. In turn, others were happy to receive positive feedback or were fascinated that the TV program reacted to them personally.

[24]The overall result of a SUS questionnaire is a numeric value between 0 and 100 that estimates the system's usability. A score of 68 is the average value. All values above 68 imply that the tested system already has good usability, needing only a few adjustments, while all values below 68 suggest more improvements to the system. We calculated the "raw" SUS score per condition for each participant using the following formula (with X = participant-ID and FX = one of the 10 SUS scales):
SUS-RAW(X) = (F1-1)+(5-F2)+(F3-1)+(5-F4)+(F5-1)+(5-F6)+(F7-1)+(5-F8)+(F9-1)+(5-F10)
The final SUS score per participant and condition was calculated as follows (with X = participant-ID): SUS(X) = SUS-RAW(X)*2.5

[25]The short version of the User Experience Questionnaire [26] consists of eight measuring items, each corresponding to a five-point Likert-scale defining a range between two opposed adjectives, e.g., "simple" and "complex". We calculated these eight items' mean, variance, and standard deviation. Furthermore, we determined the two UEQ scales: The pragmatic quality and the hedonistic quality. The pragmatic quality includes parameters describing the usability of a system (efficiency, clarity, and responsibility), and the hedonistic quality defines the emotional and aesthetical traits of the overall user experience (attractiveness, novelty, and stimulation). Each quality is identified by calculating the combined mean of their four items. Values between -0.8 and 0.8 are neutral, while values above this interval are positive and below are negative.

Overall, the combination of interactive AR content on a phone and a TV format was well accepted. One participant mentioned they would like it more if the AR content could be mirrored on the television screen. Another participant paid more attention to auditory information on the TV than visual information, possibly because they were concentrated on their task on the second screen.

The visual elements of the TV were more passive during certain parts of the whole episode so as not to overload participants' visual processing channels. The majority (6/8) coped well with the main visuals on the second screen and relevant audible information sent from the TV (combined with passive visuals).

5.6.3 Semi-Structured Interviews. The whole study was completed with a semi-structured interview containing seven questions regarding the overall concept, the collaboration with the show host, the actual target audience, and technical devices. All interview sessions were audio-recorded for transcription purposes after the participants provided written consent. Each discussion was then transliterated and analyzed using the "Rainbow Spreadsheet" approach for rapid qualitative analysis[52]. This method works by listing all interview statements in an Excel sheet, each new statement in a new row. Each participant is assigned a column and a color, which is used to mark which participant made which statement. If multiple participants stated something similar, the row got multiple color marks. This gave a good overview of where the participants shared the same opinion or where they had different thoughts about a topic. In the next paragraphs, we will present what was discussed during the interview sessions and where the participants' opinions matched.

Q1 – General Opinion about the Concept. All participants commented positively on the overall concept of *MINT Busters*. The interactive TV show was perceived as "innovative", "exciting", and "like a mini-game" (P01). It was described as "definitely something different" and "a completely new experience" (P07). The participants enjoyed being active during an edutainment show and not just being passive consumers. Three of them emphasized that it "is valuable" that you are "not just passively consuming", but you can put your new knowledge into practice "with tasks" (P01-03). Five participants mentioned a "better learning effect by trying out the theoretical content", a "better lasting understanding", and "more learning fun" while "repeating and exercising" (P02-06). It was also brought up that "children [could] learn much better" with it (P05). One participant also said that the style of the show was "very pleasant" and "suitable for children" (P08).

Q2 – Ranking of the Four Collaboration Styles. Next, the participants were asked to rank the four collaboration styles they experienced in the main study by assigning them to a ranking from 1 (the best) to 4 (the worst). Table 3 shows the final ranking of the evaluation based on the number of mentions for each rank: Condition B - *Coaching* was most mentioned as rank 1 (4/8) and finished first, condition C - *Modeling* second (3/8 ranked it as 1st), condition D - *Collaborating* third (mentioned once as 1st place), and condition A - *Scaffolding* last (mentioned the most as 4th place by 6/8 participants). The participants were also asked to state reasons for their ranking decisions. The feedback from the show host in the coaching condition was the most helpful for them to solve the task as it was "demanding" and "giving freedom to trial and error" (P02). It was also described as "intervening" when "the moderator participates" in the task (P05). They liked the "step-wise praises" because it "was just motivating" (P05). Condition A–*Scaffolding* was rated as the least favorite with the least amount of interactivity because "it could perhaps lead to misunderstanding" when "you don't know what to do" (P08). Several participants suggested combining the variants into one solution: "Demonstration and feedback are both really important. [...] I could imagine a combination of both very well" (P03, P07). According to them, it could also depend on the child's age. Older children could solve tasks independently, but younger ones might need more support to work on the given exercises (P07-08). Furthermore, they discussed if it would be possible to integrate a customized or "gradational" combination where the interactivity and collaboration could be adjusted to each child's needs (P06, P08). With that, it would be possible to support the children more in the beginning and then gradually let them do tasks more and more on their own.

Table 3: The four different collaboration styles (A: "Scaffolding", B: "Coaching", C: "Modeling", D: "Collaborating") tested in our main study were ranked by each participant. The final ranking is based on the number of mentions of each position per collaboration style. Condition B got the highest rank, while Condition A got the fourth place.

Final Rank	Cond.	1st	2nd	3rd	4th
1st	*B*	4	3	1	0
2nd	*C*	3	1	3	1
3rd	*D*	1	2	4	1
4th	*A*	0	2	0	6

Q3 – Interactivity with Augmented Reality. The feedback, in particular, gave them a feeling of constant "support" (P0). It "was good to hear when you did something right" (P02-04). "When you got the hang of it, it was fun although it was math" and it "encouraged to get into problem-solving" (P05). During the study, the AR application didn't always work as expected and had some minor here and there to track the paper cards. Three participants mentioned these issues but didn't depreciate the application as they knew it was a first prototype (P01, P04, P06). That led to the important topic that such an application should work smoothly in the final product and have a good support service because children should be supported in handling troubles without needing deep technical skills (P01). For future television, they could envision this concept very well, but for the present, they see this concept more on today's online platforms like Twitch[26] and Youtube[27] or on streaming services like Netflix[28]. Overall, the "concept could work really well in the future as a TV show, and then you put on your glasses"(P06). It was also pointed out that the whole series should be easily accessible for all children who want to watch it. *MINT Busters* should work "also without an app or phone" and "without additional materials" like paper cards "to not exclude children without the devices" (P07-08).

[26]https://www.twitch.tv/
[27]https://www.youtube.com/
[28]https://www.netflix.com/

That would also be tied to the expenditure of time and money that could hurt the show's spontaneous nature.

Q4 – The Show Host Minty. Minty was perceived well by all participants. She was described as "very suitable" (P01, P03, P08), "friendly" (P02, P04, P05), "suporting", and "likeable"(P02, P04, P05). She has a "very pleasant, comfortable and warm voice like in an audiobook for children" (P02). Her appearance was designed in a "visually pleasing" way and matched the overall style of the TV show. Four participants liked that she was female and her style was more diverse with her "colorful hair" hairstyle and skin tone (P05, P07, P08). The clay figure style was criticized as one participant was not sure if this style would be well received by children today (P06). One participant would prefer a real person (P02). Another participant said he didn't notice her much because he focused more on the visual parts around her (P04). He added that, in his opinion, this show could also work without a moderator. Other participants experienced having her as an attachment figure as very good and important by having her as a "main character" who accompanies you through the story and the topics(P02, P05, P06). While one participant found it positive that the moderator is female, another female participant mentioned that she would like the show to have an alternative male character so that "boys could have an attachment figure as well" (P07).

Q5 – The Target Audience Children. The participants were asked to put themselves in their younger self's position and to imagine if they would have enjoyed such an AR-supported edutainment show as a 10- to 14-year-old. Five participants were sure children of that age group would like the show format (P01, P02, P04-06). As children already have their own smartphones very early (P04, P08), they could be interested in a combination of visual learning and "haptic tasks" that are prepared in a playful and funny way (P02, P04-06). Three of them were more critical and said the concept wouldn't be suitable for the targeted age group and would work better with younger children (P03, P07, P08). They also discussed that children at this age would spend much of their free time with apps like TikTok[29] and engage a lot in current trends, particularly dance trends. It was highlighted that the concept should go with the spirit of the time and tie in with current trends like Fortnite[30] (P01, P03, P07, P08). This thought was pursued until an idea came up that the show could be linked to a TikTok account where the show could be advertised or additional content could be placed (P08).

Q6 – Is Something Missing? We asked the participants if they missed something in the whole concept. They asked for further developed plots with more relatable everyday stories (P01, P03). If the plot of each episode was extended with alternative storylines, the viewers could unlock certain paths of the story by solving the interactive tasks (P03) or unlock additional content (P07, P08). Furthermore, they wished for the AR content to be mirrored on television (P02) as well and for AR to be used as motivation to integrate more body movement into the learning process instead of solving the tasks while sitting (P04). They also thought about the concept of the show host passing the fourth wall and walking into the living room. In their opinion, it would work great if the moderator was the same size as the child or as small as an action figure so that they are not irritated or afraid of them (P06).

[29]https://www.tiktok.com/
[30]https://www.fortnite.com/

Q7 – HMDs or HHDs for AR?. All participants were satisfied with using the smartphone as an AR device. According to one participant, it provided a "haptic component" to the interactive experience and would be accessible to a greater audience when compared to HMDs (P02, P05, P06). One participant mentioned that she would prefer a tablet because of the bigger screen (P03). While discussing the HMD solution, they would envision a better immersion, better visibility of the holograms, a hands-free and, therefore more effortless interaction, and more interaction possibilities (P01, P04, P06). However, they worried that the headset would offer a worse perception of the physical world (P05), that it could be too complicated for a child to handle (P03, P05), and that the headset itself is a device that's still not widely spread as a consumer device (P06-08). On the other hand, they thought about the headset as an alternative device that the children use only for this purpose so that they are not distracted by any notifications from other apps and the parents would be able to control their daily smartphone usage better (P06-07).

6 DISCUSSION

We discuss the educational benefits of CoARTV experiences and the implications of the results of our user study. Based on the implications, we state design guidelines for integrating collaboration in future CoAR-TV applications. Afterwards, we clarify the limitations of our work and provide future research questions.

6.1 Educational Benefits

The insights of our interviews reveal that AR-supported edutainment experiences can have educational benefits. The playful and interactive nature of our concept was perceived as motivating and enjoyable, which are key prerequisites for an effective and enduring learning outcome. The show host *Minty* motivated the test audience to participate in an informal, relaxed learning session about a Math topic. The participants found themselves in an active role in the TV experience and could directly implement what the show host had taught them in an actual gamified task. Augmenting the learning content of a television show with interactive and three-dimensional virtual elements led to a deeper understanding of the presented concepts. Furthermore, a show host who reacts to the viewer's inputs and provides feedback could encourage the audience to feel competent enough and engage in STEM topics. Thus, various edutainment formats could benefit from integrating AR-enhanced interactive and integrating collaborative show host into their concepts.

6.2 Implications and Design Guidelines

Based on our study results and the conversations with the participants, we can approve condition B "Coaching", which consisted of the show host reacting with feedback to the participants' inputs, as the best-accepted collaboration technique. Condition C "Modelling" ranked second and got mentioned three times as most preferred collaboration style as well as condition D "Collaborating" ranked third with one mention as first place. Considering that, we propose these two collaboration styles in addition to the reactive feedback of condition B. As already discussed with some participants, we assume that a combination of feedback on the user input, modeling problem-solving strategies, and active engagement of the show host in the problem-solving process works well in a CoAR-TV edutainment show format. This combination highly depends on the target audience and the individual needs of the viewer.

We propose always using some kind of auditive and/or visual feedback of the show host reacting to the viewer's input. This kind of feedback can be displayed by the TV and the AR display. If the problem the viewer has to solve is too complex for their knowledge and skills to solve on their own, we recommend using modeling to let the show host explain one or more ways to solve it. This can be a full step-by-step guide but also in explaining individual steps in multiple sessions or on demand when the user asks for it. If the viewer needs it, the show host can actively take part in the task but should still take the role of the supporter and not the leader to keep the viewer's autonomy as a learner. Therefore, we propose that the show host intervene only at the beginning of a topic or only when the viewer asks for help when this strategy is used.

In our study, we focused on using a mobile device as an AR display because it is the most accessible AR device for children and adults at present. Observing the current hardware releases (e.g., Apple Vision Pro and Meta Quest 3) and the new revival of the AR/XR trend, we assume that in the next decades, there will be more AR glasses in regular households, leading to higher accessibility of them. Our contribution is independent of the AR display and could be implemented for any other AR device.

Besides edutainment for children, these collaboration strategies can be generalized to other TV formats. The most obvious use case is edutainment formats for adults. There are also existing documentaries (which we also consider to be a type of edutainment format) that include interactive storytelling that could benefit from AR-enhanced collaboration techniques to enrich the learning experience with three-dimensional content and innovative interactivity. The interactive documentation "You vs. Wild"[31] by Netflix is an example that combines the adventurous story of the main character Bear Grylls teaching survival skills with interactive storytelling based on the viewer's decisions.

It would be possible to integrate AR-enhanced collaboration into gaming shows like "Who Wants to be a Millionaire?"[32] that already feature the show host and contestant collaborations with the co-located audience and the remote audience in the living room.

For public broadcasters, it could be particularly interesting to start working with CoAR-TV experiences in the context of edutainment shows and other formats. Using innovative technology to enhance their already existing program or developing new formats will make their medium future-proof and more interesting for the younger audience whose interest is more focused on streaming content, gaming, and social media than on classic television.

Integrating a CoAR-TV into a live show scenario could also enhance such formats. At present, we assess such integrations as more suitable for live streaming on online platforms like Twitch and YouTube than on broadcasted formats due to the technical hurdles of implementing interactive content to classic TV broadcasting. Online live-streaming platforms already provide forms of collaboration and interaction between streamers and their audience, which could make it easier to build on.

Social media platforms like TikTok, Instagram[33] and Snapchat[34] have already integrated Augmented Reality successfully in their user experience in the form of camera filters (ranging from cosmetic face filters to whole games), and their audience accepted it well over the last decade. Edutainment content providers, like Netflix, that already partially offer interactive edutainment shows could benefit from integrating such features from these well-established platforms that offer certain software frameworks and the architecture for quick AR solutions.

6.3 Limitations

Since we wanted to gain quick insights for the first prototype of our concept before starting a whole production of it with an interdisciplinary team, there are some limitations to our contribution.

We decided to conduct our first study with young adults and not with the actual target age group since children can be more critical users than adults. Instead, we invited young adults to test our concept to prepare for a following study with the target audience and a refined, more professional production. Young adults allowed us to get feedback from people who still remember their childhood so they could step into the role of a child during the test. The small sample size in our study was chosen because we wanted to get deeper insights into the participant's thoughts with a longer semi-structured interview. In a follow-up study, we plan to test a further developed version of the prototype with a greater sample size to substantiate our findings further.

We decided to test only one interaction technique for the AR part of the prototype to be able to focus on the concept evaluation. Alternative interaction techniques without the need for additional paper cards and maybe alternative devices should, therefore, be compared in a user study.

In our study, we focused solely on the collaboration between the show host and the viewer as a proof of concept and a variety of collaboration techniques rather than a fully developed interactive story script. The lack of interactive storytelling with alternative paths must be compensated in a following test session based on a fully developed story script and application.

Besides that, a three-dimensional representation of the show host to visualize the passing of the fourth wall was not implemented to keep the concept closer to the viewer's viewing habits. Designing and building such a character that could step out of the TV includes the possible rethinking of the show host character in collaboration with an interdisciplinary team. However, the passing of the fourth wall can be another interesting research topic to look at further.

6.4 Future Research Directions

Based on our contribution, we propose the following directions for future research in CoAR-TV.

Besides reiterating our overall interactive show concept, future work could investigate AR-enhanced edutainment related to interactive storytelling by integrating more input-reactive content

[31] https://www.netflix.com/title/80227574
[32] https://www.imdb.com/title/tt0211178/
[33] https://www.instagram.com/
[34] https://web.snapchat.com/

and comparing different approaches to enrich two-dimensional audio-visual content with three-dimensional interactive visuals. Interesting future research directions could be investigating different possibilities of using AR as input for interactive stories and examining different ways of breaking through the fourth wall meaningfully without disrupting the audience's experience.

Aside from that, there is a need to work on a full prototype production with an interdisciplinary team consisting of educationalists, interaction designers, producers, and software engineers to gain insights on certain workflows and challenges compared to a regular edutainment production.

It is also necessary to develop design guidelines for CoAR-TV productions to support practitioners in their ideation phase, as there are still few works from which to get inspiration. These guidelines should include best practices for interactions with AR and proposals on using AR in combination with a TV device for interactive storytelling and dissolving the fourth wall.

Since our work focused on evaluating collaboration techniques in a CoAR-TV scenario, future research could investigate alternative interaction techniques, devices, and integrating body movement into the experience.

7 CONCLUSION

Our work focused on defining and comparing collaboration techniques in the context of AR-supported edutainment formats for children. We deviated four different collaboration techniques from the Cognitive Apprenticeship Model by Brown et al. [7] to enable collaboration between the host of the edutainment show and the viewer in the living room. As a use case for our user study, we designed an expert-reviewed edutainment show concept and a prototype featuring its pilot episode addressing a young audience between 10 and 14 years old to enthuse them about STEM concepts. The results of our user study show that the overall concept was well accepted and that the feedback-based collaboration style worked the best. However, we recommend a combination with the remaining collaboration techniques to provide the best solution adapted to the target audience's needs. We hope our work encourages further research in the context of asynchronous collaboration in Augmented Reality in relation to television and other scenarios.

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