Augmentation not Duplication: Considerations for the Design of Digitally-Augmented Comic Books

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ABSTRACT

Digital-augmentation of print-media can provide contextually relevant audio, visual, or haptic content to supplement the static text and images. The design of such augmentation—its medium, quantity, frequency, content, and access technique—can have a significant impact on the reading experience. In the worst case, such as where children are learning to read, the print medium can become a proxy for accessing digital content only, and the textual content is avoided. In this work, we examine how augmented content can change the reader's behaviour with a comic book. We first report on the usage of a commercially available augmented comic for children, providing evidence that a third of all readers converted to simply viewing the digital media when printed content is duplicated. Second, we explore the design space for digital content augmentation in print media. Third, we report a user study with 136 children that examined the impact of both content length and presentation in a digitally-augmented comic book. From this, we report a series of design guidelines to assist designers and editors in the development of digitally-augmented print media.

CCS CONCEPTS

• **Human-centered computing** → **Mixed / augmented reality**.

KEYWORDS

Augmented Reality, Comic Books, Digital Augmentation

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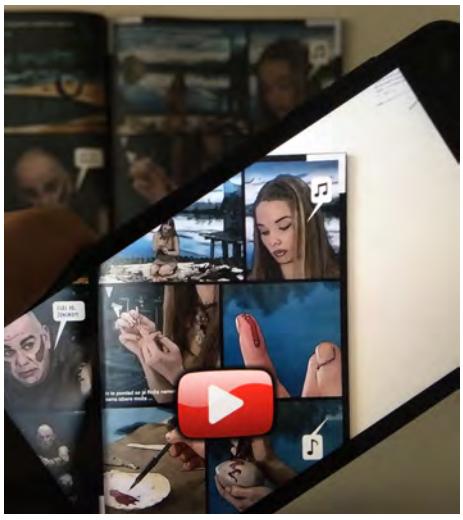

Figure 1: The "Bobri Voz" comic book page 'comes alive' frame by frame when watched through the phone's screen.

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1 INTRODUCTION

Digitally-augmented comic books ('AR comics', Figure 1) combine the traditional paper comic format with Augmented Reality (AR). Typically, the reader can access animated sequences (audio and video) of the page's frames or other online content via a mobile device. Comic book writers and illustrators see this as one approach for encouraging young readers to continue to engage with printed comics.

Despite the large body of work into AR [23, 46], and AR Books [14], there is little understanding of how authors and illustrators should design for this combined physical/digital medium. Specifically, it is unclear which storytelling approaches to use (augment, replicate, or add to existing content) or how digital content should be integrated into the reading flow (how much and how often). Further, it is unknown how these design decisions impact the holistic reading experience.

In order to better understand this design space, and the implications of these design decisions, this paper provides insights into the design and use of digitally-augmented comic books through real-world deployment statistics, a design-space exploration, and a controlled user study. Overall we saw that duplication in real world usage encouraged 37% of users to stop reading and resort to watching videos. In a controlled study this value drops to 15%. Most participants consumed all available content even if duplicated, which helped them to perform better at retention test. In contrast, when providing shorter exerts to augment the comic, none of the participants ignored the printed medium.

To summarise, this paper contributes: (1) An analysis of the real-world use of an AR comic; (2) A description and discussion of the design space of digitally-augmented comic books; (3) A user study with children (N = 136) to evaluate different aspects of the design space and; (4) A series of design guidelines derived from our findings. These contributions go beyond previous work by providing the first analysis of real-world use of a digitally-augmented comic book, the most extensive design-space exploration to date, and the first large-scale study exploring design decisions in AR comics.

2 RELATED WORK

Historical Context

Printed materials have been a mainstream medium for nearly half millennium and are recently changing and adapting to digital technologies. For example, publications often have digital counterparts (e-books, on-line newspapers) or have moved completely on-line. In the case of scientific publications it has been suggested that on-line versions should be augmented with animated figures [16]. Nevertheless, printed materials are often preferred by users since they offer various advantages such as portability, flexibility, and tangibility [28]. It is these advantages that have contributed to augmentation of printed materials with digital elements—mainly with the advances of mobile AR. This mix of printed material's physicality and interaction possibilities of digital augmentation has been used for three often overlapping purposes: education, storytelling and entertainment.

Augmented Reality (AR) in Journalism

AR is regularly used in journalism as a vehicle for storytelling [30]. Various approaches include overlaid simple, interactive, and geo-tagged graphics, photographs and videos to provide additional context to news and information, and use of location information available via AR and social media to identify potential sources for stories. Examples include Wire magazine featuring an audiovisual cover (https://www.thewire.co.uk/rewind2017app), The New Yorker (featuring artistic audiovisual 3D video), ELLE (featuring interviews on covers), W magazine (showing music videos), Die Welt (visualising 3D graphs, buildings and similar content), and Metro (showing film trailers, various videos, photo galleries).

Augmented Reality in Education

AR printed materials (and AR in general) provides numerous benefits in teaching and learning environments [3] as it enables students to: (i) explore and engage with content from various angles [22]; (ii) interact with content, which is otherwise impossible to be experienced first-hand [34]; (iii) understand spatial relationships and interactions of elements within a 3D space [35]; (iv) seamlessly interact between the real and virtual worlds [3]; (v) enhance creativity and imagination [25] and; (vi) reinforce collaboration [4, 21] discovery-based learning, object modelling and skills training [45].

Book-based Augmented Reality

An early system describing the use of AR in books showed augmented 3D objects pop-up from the pages as early as in 1998 [32]. Since then, various topics and approaches have been used in augmenting school books. The research community has suggested, developed and explored systems showing AR in books covering for example mathematics (e.g. showing geometric shapes) [24], physics (e.g. depicting complex 3D concepts) [11], astronomy (e.g. exploring the workings of the solar system) [34, 36], engineering [29], and history (e.g. intensify the description of struggles of European settlers in New Zealand) [15]; each exploiting one or more of the aforementioned advantages of AR.

AR is also utilised as a medium to enhance immersiveness in story books. Such books usually feature animated characters and virtual pop-ups. Examples include the Magicbook [5], which enables readers to traverse from real to augmented and virtual space with a book as a tool, Virtual

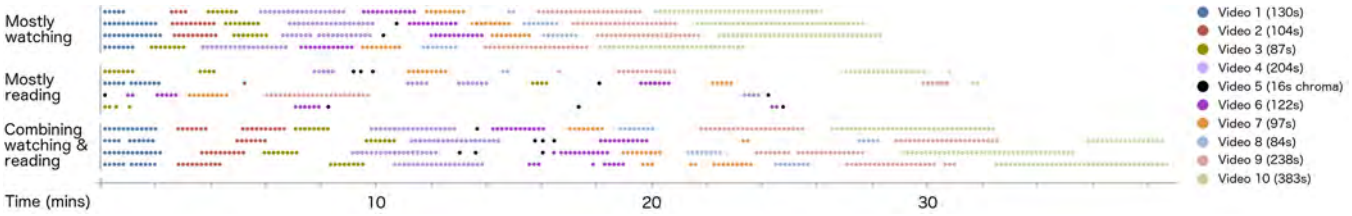

Figure 2: Sequence graph showing examples of AR Comic interaction patterns. Each row represents one user's engagement and each coloured dot in a row represents 10s of viewed video. Each colour represents a different video. Top: mostly *watching* (W) occurs when users skip pages and watch only the videos in sequence (there are almost no blank spaces between video sessions). Middle: predominately *reading* (R) occurs when users are assumed to be reading (large time gaps between videos), skip videos and/or stop them early. Bottom: combining *reading and watching* (C) occurs when users watch the videos in sequence and read, which is visible by longer time gaps between the videos.

pop-up book [39], utilising the book's pictures as markers to show virtual 3D objects, Interactive storybooks [10] aimed at early literacy education and collaboration, and The Haunted Book [33] that animates the illustrations of a poetry book. Outside the research community, publishers have also started to explore the potential of AR in books with the advances in various commercial AR frameworks and SDKs. In 2011 an AR book titled *The Future is Wild: The Living Book* was presented at the Frankfurt Book Fair that integrated videos, 3D models and other AR content. Since than, numerous books emerged integrating AR content with physical elements of the books.

Interaction with Augmented Reality

Interaction emerged early as an important factor for manipulating digital elements. Beyond moving and rotating digital objects (e.g. by moving the marker), prototypes have explored how users can move book-based characters around to complete tasks and progress the story. These techniques used controllers with markers attached to them [10], triggered events by bringing tangible objects to designated book pages [11, 15, 18, 44], moving interactive parts of the pop-up book to reveal additional information [31], or by interacting with multiple users [10, 15].

Another common augmentation is to play videos on print medium. These are typically played while print medium is in view of the device and stop playing when out of view. As this may lead to arm fatigue previous work explored alternative options such as freezing the real-world view [26] or transitioning to a digital copy of the physical media [17].

Yet another area of interaction is content creation where users "co-create" the book through real-world creative activities. Examples include creating digital notes in a physical book [37], the *Interactive AR colouring book* [8] that creates pop-up animated sequences of the children's colouring, and the *AR coloring book App* [27, 47] that allows children to express their creativity through colouring a colouring book page while the animated character is coloured in real-time.

The Impact of AR on End-Users

With the advances of affordable mobile AR hardware and off-the-shelf AR libraries, the focus has shifted from technical development to the effects of the technology on users. Building augmented books has become easier for wider research community and current works describe how such technology influences its readers. Studies have for example looked at a "positive and measurable" impact an AR book had on the spatial ability of mechanical engineering students [29], the affordances of interacting with physical objects that provide a "desirable naive physics" notion in the context of AR books [19], the impacts on cognitive load and motivation while studying from AR books [7], the effects on the collaborative experience while reading AR books [1, 13], and the positive effects of augmented books on learning outcomes [43].

The current body of literature has not yet explored the design of comic books as mixed-reality medium despite the fact that comic books are ideal candidates for augmentation as they are based on conveying the story with visual elements. While commercial products that digitally augment/animate comic books are available such as Marvel AR[1] and Black Eyed Peas' Comic Masters[2], little is known how people interact with such digital content 'in the wild'—this is required to better support design decisions and how these decisions influence the reading experience. To expand the body of knowledge in this area we conducted an 'in the wild' study and a controlled study with 136 children with 3 different designs of comic augmentation.

3 REAL WORLD USAGE

To understand how an AR comic book is used 'in the wild' we worked with the artists and publishers of the commercially available digitally-augmented comic book "Bobri Voz" to log

[1]https://www.youtube.com/watch?v=FE4uPnk1zUI
[2]https://www.youtube.com/watch?v=OB7oAts0GR4

	C	RC	WC	W	RW	CW	R	WR	CR	M	SUM
Only one mode	15	0	2	17	5	5	7	8	6	11	76
%	19.74	0	2.63	22.37	6.58	6.58	9.21	10.53	7.89	14.47	
All finished with this mode	17			27			21			11	76
%	22.37			35.53			27.63				

C - Combined
W - Watching
R - Reading or dropout
M - Mixed & could not be defined
Two letter combination means the pattern started with one and finished with another pattern (e.g. CW means the pattern started with Combined and finished with Watching)

Table 1: AR Comic interaction pattern summary. The top row shows how many people exercised a particular pattern (combinations of C, W, & R show that the pattern transitioned during engagement). The bottom row shows how many people ended reading with one of the three patterns C, W or R.

all accesses to the digital content. This section reports our findings.

The AR Comic, graphical design and video content

The comic is based on an animated film and tells the story of the invention of a wheel by people who lived in the area of Ljubljana's marshes. The story is fictional, but inspired by the real 5200 years old wheel found in the area. At the time of the study the comic was available in book stores around Slovenia and public libraries across the country.

The comic book size is A4, has 39 pages and 167 frames; 10 of these frames are specially marked as being digitally augmented (see Figure 3 b). The digital content is accessed through an augmented-reality application for smartphones. Within the app the user points the phone's camera at specially marked frames and clicks the scan button. If the frame is recognized as augmented, a play button appears on-screen (see Figure 1) and the user can begin watching the integrated video or proceed to full-screen mode. The embedded videos duplicate the comic book content from previous augmented frame up to the currently scanned frame and thus replicate the whole comic book. The total length of the video content is 24 minutes and 25 seconds.

Data Collection

The primary goal of the study was to uncover how such integration of digital content influences the reading pattern of the user. We hypothesized that duplicating the whole comic with embedded videos visible with mobile AR application will discourage users from reading the book.

To test our hypotheses, we integrated user engagement tracking into the application. The application was distributed through the Google Play store. The tracking system captured usage data over a period of 1 year and recorded 590 minutes of video watching though 2538 video events or sessions. The application also captured 5349 general application events, such as: application start and close events, various button clicks, and tracking error events.

To delineate individual interaction patterns we grouped sessions (video events) into sequences. On each phone we considered a new sequence if more than 25 minutes elapsed between two interactions (based on the time needed to finish reading the book) or if a sequence exceeded 70 minutes. We also dropped all sequences with less than 4 sessions since it is difficult to draw anything from such short interactions and ended up with 76 sequences made on 62 phones (of which 50 generated just one sequence). We have no means to tell if the same person used a particular phone more than once, multiple people used it simultaneously, or different people in succession (e.g. siblings using parents' phone) and will thus focus on sequences only.

Results

Sessions per sequence varied based on which and how many videos users watched. Out of 10 videos, users on average opened 5.3 (median 4) videos and watched 10.5 [43%] (median 5.7 [23%]) minutes. To better understand interaction patterns (through which reading patterns could be anticipated) we visualised the log data on a sequence graph (see Figure 2). Each dot in the graph represents 10 seconds of video watching. The sequences were individually classified by two authors of the paper looking for one of the following patterns:

Watching (W): User omits reading and focuses only on watching videos, Figure 2 (top).
Combining (C): User combines watching videos and reading, Figure 2 (middle).
Reading (R): User predominantly reads and only opens videos for a short period, Figure 2 (bottom).
Mixed (M): It was not possible to categorize the pattern.

Each sequence could be marked with multiple patterns where the order resembles the change of user behaviour within a given sequence. The authors compared and aligned their classification results which are captured in Table 1. The classification results show that the highest number of sequences demonstrated the watching pattern (W=17 [22%]), followed by the combining pattern (C=15 [20%]) and the first watch then read pattern (WR=8 [11%]). When looking at the pattern sequence ended with if users transitioned during engagement an increase in the difference between watching and combining pattern shows up (W=27 [36%], C=17 [22%]).

This suggests that some users realised that the whole story is duplicated and resorted to watching the videos only.

We acknowledge that we do not know if and how much people read before and after they interact with the app. We assume they start as readers as they do not initially know if or how AR is integrated into the book and can observe interaction patterns only when they start using the app. By observing the interaction patterns we can conclude that the evidence supports our hypothesis (total duplication discourages reading) for a third of the cases (36%). Moreover, a quarter of cases ended in reading (28%). Such interaction patterns defy the purpose of digital content within the printed comic book.

In the following section we explore the design space for digitally augmented comic books to understand how different design decisions may influence reader engagement.

4 DESIGN FACTORS FOR DIGITALLY AUGMENTED COMIC BOOKS

The effective augmentation of physical comic books with digital content hinges on four key factors: the storytelling approach; how the digital content is integrated into the reading flow; the presentation medium and; the method for accessing the digital content. This section explores the design of these factors and the implications of different choices. The design space is derived from our experiences working with media artists who create augmented comic books and our understanding of issues from the real-word deployment. Besides the parts that are novel and are not referenced, we added work from the related literature, notably Grasset et al's taxonomy [14], to present the topic as a whole.

Storytelling Approach

The storytelling approach determines how the digital content changes the story's narrative and the reading experience.

Digital Content Purpose. Digital content can be used to augment, replicate, or provide additional storytelling material not shown in the printed comic. *Augmentation* adds an additional modality or view onto the printed representation. This might include audio to create mood or the 3D rendering of a printed character. Augmentation is typically used to increase engagement or to better convey the content designer's original intent, but does not change the story delivered. *Replication* provides an identical storyline through a digital representation. A typical example of augmentation is to turn the frames of a comic book into an animation. *Additional Content* provides new content or storylines that are not present in the print media.

Presentation Genre. The digital content's genre can match or contrast the style present in the printed media. This includes the narrative approach (e.g. first-person vs. third-person narration) and style of audio/visual presentation. When the digital content's genre matches that of the printed content, it provides the reader with an immersive, flowing experience. When one of the genres change, it encourages the reader to view the story from a different perspective, getting them to reflect on what they have read, seen, and heard. For example, the digital content that accompanies a hand-drawn comic book could be shot as a documentary, providing a factual basis for the story.

Interaction with Content. Digital content may be passive (e.g. a static image, video- or audio- stream) or active (e.g. a 3D model that can be examined from multiple angles [5] or by providing interactions that allow story-line manipulation [10]). The addition of interactivity can lead to greater engagement and immersion, but also has the potential to distract away from the main storyline.

Integration of Content into the Reading Flow

The placement and timing of augmented content can significantly impact on the reading flow of the comic. Poor integration of this content can lead to a bias towards one or the other media or, in the worse case, abandonment of either the printed or digital content. There are two key characteristics to consider: the spatial position of digital content and the properties of individual content clips.

Spatial Position of Content. There are two key considerations for spatial positioning—the *access position*, the physical position on the page where the reader must register their interest in digital content (interaction methods for this are discussed below) and the *viewing position* where any visual content is shown. These positions can be the same or different, each influencing the reading flow of the comic [40].

The placement of digital registration points (either implicit or explicit) directs the reading flow. Registration at the start of a page facilitates mood- and scene-setting, while registration at the end of the page is used for content reflection. Registration that occurs within the page will interrupt the reading flow, breaking immersion, and should be designed to provide context or relevant content that encourages the reader to return to the next frame or block.

The registration position also impacts the spatial position of any visual digital content. Within-page registration typically indicates contextually relevant content and it would be expected that the digital content is presented within that spatial context. Registration points at the start or end of the page may or may not indicate contextual relevance, and digital content can then be placed anywhere on, above, or outside the page [14, 41].

Frequency, Length, and Volume of Digital Content. Closely related to the purpose of the content is the frequency of

appearance, length of digital augmentation, and the total volume of digital content. Frequently appearing digital content (e.g. every two or three frames/blocks) can lead to significant context switching between the printed comic and the digital content access device. Short clips may also become 'unimportant' for the reader who wishes to focus on the storyline. The overall balance of digital vs. written content is also important to maintain the desired level of engagement with both media [13, 15].

Presentation Medium

Augmented Reality extends beyond the traditional overlay of visual content to include audio and haptic output, and links to other content. This has implications for both the storyline and the reading flow. Visual content will require some 'removal' from the physical page (e.g. holding a device to view the digital content), interrupting the flow of reading. Audio and/or haptic augmentation without visual content may remove this barrier to reading, but suffices the fidelity of visual representation. Using all three modalities can enhance the immersion of the augmentation, but moves the reader further away from comic-book experience.

Access Method

In this section we examine the technological approaches for accessing digital media, and how prerequisites can be imposed for accessing the digital augmentations. While this article focuses on access through commodity devices (i.e. mobile phones), head-worn displays [38] and projection [2] provide a different array of content access approaches.

Technological Approaches. There are three main technological approaches to accessing digital content with a mobile phone: (1) Vision based recognition; (2) Proximity-based differentiation; (3) Manual content selection. With vision-based approaches, the reader holds their mobile device such that the camera captures the 'active' area of the page. Computer Vision can then be used to identify markers. These markers can either be explicit fiducial markers [12] (e.g. QR codes) or implicit, such as the frames in the comic. For implicit markers the reader must still be made aware of the embedded digital content. For short content the mobile device is continuously held in place while the digital media is rendered. For longer content, once activation is complete, the user does not have to continuously hold the phone in place.

Proximity-based approaches (e.g. NFC [42]) typically require the mobile device to be placed on a particular area on the page. This has the disadvantage of covering page content, however this is often more suitable for 'short' augmentation (such as short audio or video clips) that relate to that particular frame of the comic. This is because proximity-based method is faster at accessing digital and more user-friendly if compared to vision based approaches (e.g. placing the phone on top of the image vs. pointing and focusing the camera at an image).

Accessibility. To encourage engagement with the physical comic, access to digital content can be limited until certain conditions are met. For example, time-out periods may be used to ensure reading of the text occurs between viewing augmented content (eye-tracking could also be used to achieve the same effect) or rapid-fire questions can track engagement with the textual content.

Summary

The design factors outlined in this section have a significant impact on the value and resulting engagement in the comic reading experience. To begin formalising these impacts, we designed a user study to understand engagement and retention when school students read different versions of an augmented comic book.

5 USER STUDY

The goal of the controlled user study is to understand how different approaches of digitally augmenting a comic book impact user engagement and the reading experience. We used the same comic book and video materials as in the real world study. To test different approaches we designed four different augmentation conditions:

Reading (Figure 3a): control condition, where the comic books were not digitally augmented.

Default (Figure 3b): repetition of real world study (for more detail see AR Comic section)

Teaser (Figure 3c): NFC tags were placed on the upper-part of each left hand side page. When a phone was placed on the tag a full-screen short video was launched illustrating the first 20% of the upcoming double-page. Each video acted as a "teaser" to invite users to read the rest of the double-page spread. The NFC tag was marked as a phone icon with a play button in it.

Animated Frames, AF (Figure 3d): this condition used two activation methods. The first was animated pages marked with four white corners. When viewed through the phone screen the frames "came alive" with moving the integrated video from frame to frame or hide it when direct resemblance to the frame is lost whilst the audio keeps playing though the whole sequence. The user is guided to currently augmented frame by highlighting edges of the active frame. The second was sound-rich frames depicted with NFC tags marked as phone icons with a sound icon in it. When the phone was placed over them a short, contextually relevant and sound-rich video was shown. The most dynamic

Figure 3: The four study conditions. (a) Reading only condition; (b) Default condition (as per in in-the-wild study) that duplicates with video the previously read content, activated by scanning the frame through the phone screen; (c) Animated Frames, where frames 'come alive' sequentially, activated by viewing white framed pages through the phone or with NFC tags showing short video snippets with emotional sounds; (d) Teaser condition on top frame of every odd page, when the phone is placed on the NFC tag a 'teaser' of the coming pages is shown.

and emotional pages were selected for both methods. As in the Teaser condition, 20% of all frames were augmented.

When designing the conditions Teaser and Animated Frames, we focused on the storytelling approach where the purpose of the digital content is to replicate. Our goal was to use replication in a way that should enhance the user's ability to comprehend and recall the story while trying to avoid the print medium simply becoming a proxy for accessing the digital content (as was observed in 36% of the cases in the 'in the wild' study).

We hypothesize that this can be achieved with: (i) careful placement of the digital content (e.g. Teaser condition invites the reader into the story at the beginning of every two page section); (ii) careful spatial positioning (e.g. in Animated Frames we focus on the context and show short clips or integrate video within the comic frames that have direct relevance to what is integrated/shown); (iii) appropriate frequency, and length of the content (e.g. in both designs we opt for approximately 20% of content replication).

For the Default condition, four frames were interactive. For the Teaser condition, seven NFC tags were used (one for each double-page). For the AF condition, there were five augmented pages and three NFC tags.

Participants

Pupils (N = 136, 64 girls and 72 boys) aged 9-14 from a local primary school participated in the study. The median age of participants was 11. The pupils were randomly assigned to one of the four conditions. The experiment used a between-subject design.

Procedure

The study was conducted on two separate days, with four sessions on the first day, and five sessions on the second day. Each session lasted approximately 45 minutes. The experiment took place in a classroom, the tables of which were grouped into four clusters (one for each condition). Each cluster was handled and observed by one researcher. Participants received one instructional sheet, one comic book and, for the three interactive conditions, a pair of headphones and one smartphone.

Participants were welcomed at the beginning of each session and a brief introduction was made by their teacher and one of the researchers. Participants were told that they could read the comic book as they wanted to, and that they would have to answer a questionnaire afterwards, without using the book. Participants were reminded that they would not be graded and that they should fill in the questionnaire on their own. They were then asked to read the instructional sheet explaining how the interaction technique of their condition works, as well as an example of a comic book page which they could use for training.

After training, participants were asked to read until page 17 (they would be stopped after 25 minutes, which did not occur). After reading they had to fill in the questionnaire composed of seven questions related to the story and five questions related to the pupils' preferences regarding the digital augmentation. Participants were then free to resume

	Default	Teaser	Animated frames
Average ratio (opened / available content)	93%	98%	86%
Median ratio (watched minutes / available minutes)	100%	124%	99%

Table 2: Amount of digital content consumed during the study.

their reading. Finally, each group had a 10-minutes debriefing with one of the researchers.

Data collection

The application logged video sessions, scan events, application start/stop events, frame rate and other AR specific measures (e.g. tracking errors and camera distance). We also collected the time required to read the first 17 pages, the number of correct answers to the questionnaire (max = 7) and the participants' preferences (5 questions). Students were also observed while they were reading. In particular, and based on previous pilot studies, we observed: whenever the reading flow seemed disrupted (e.g. talking to others, experiencing technology issues, etc.); how participants handled the books and phones; how participants read the book (e.g. skipping digital content, flipping pages, etc.); whether participants engaged with digital content, and how (e.g. watching a video twice).

6 RESULTS

Opened and Viewed Content

The average ratio of opened digital content ranges from 86–98% (median 99–124%)—see Table 2. The highest ratio of watched content was recorded in the Teaser condition (124%) indicating users re-watched a quarter of all the videos. This repetition of watching was also observed when analysing reading patterns (see Figure 4).

Reading Pattern Analysis

We analysed the reading patterns in the same manner as we did for the real world study. We constructed a sequence diagram (Figure 4) and classified reading styles as previously (Table 3). The classification results showed a smaller variety of observed patterns and no changes of behaviour were observed. All users are thus classified into the watching, combining, or reading patterns. The confidence of this classification is also higher than that of real world study because users diverted to reading or watching only were observed to do so.

As shown in Table 3 most of participants across all three interaction modes demonstrate the 'combining' pattern (from 76% to 83%) while Animated Frames is the only condition where the 'watching' pattern was not observed. The Table also shows that in the Teaser condition we did not observe

	Default		Teaser		Animated frames	
W - watching	5	15%	7	20%		
R - reading	3	9%			5	17%
C - combined	25	76%	27	80%	24	83%
Total	33		34		29	

Table 3: Classification of reading patterns based on sequence diagram

	Median time on content (ToC)	Median watching time (WT)	Reading time = ToC - WT	Reading time/ToC
Reading	07:30	0	07:30	100%
Default	12:52	08:42	04:10	32.38%
Teaser	08:25	02:48	05:37	66.73%
Animated frames	09:12	02:42	06:30	70.65%

Table 4: Times spent on reading and watching the digital content.

any participants who stopped using the technology (e.g. technology drop-outs). In the Default and Animated Frames conditions (AR interface) we observed eight technology drop-outs (3 [9%] and 5 [17%] respectively).

Reading Time

Table 4 presents a summary of the interaction time with the comic. The maximum time participants could spend on the comic was limited to 25 minutes. Even though users interacted with the comic for the longest in the Default condition (median 12m 52s), they only read for a median of 4m and 10s (33% of the time) as the rest of the time was spent watching digital content (median 8m 42s). The longest reading time was observed in the Animated Frames condition (median 6m 30s [71%]), nevertheless this still falls 1 minute short of the baseline Reading condition (median 7m 30s).

Information Retention

The retention scores were obtained through 10 questions participants answered after they finished reading the comic. The retention scores are presented in Table 5 and show that the Default condition produced best retention with 4/10 correct answers. The worst performance was recorded in the Reading only condition (2.9), followed by the Animated Frames (3.1), and Teaser conditions (3.4). One-way ANOVA showed that at least one of these 4 means is significantly different ($f(3,132)=4.2$, $p=0.007$). Post-hoc test with Bonferroni correction revealed significance only between means of Reading and Default condition ($p=0.007$, 95% CI [0.21,-1.99]) and a weak significance between Default and Animated Frames conditions ($p=0.05$, 95% CI[0.0004, 1.8]).

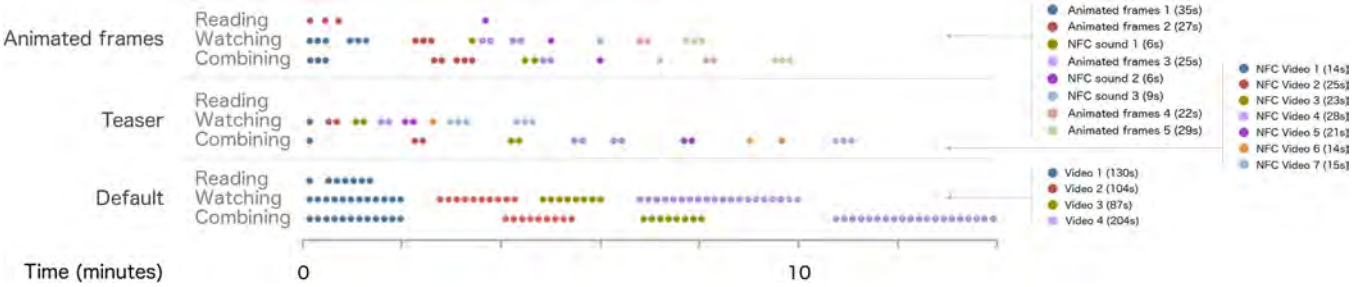

Figure 4: Controlled study reading patterns. For each condition three reading patterns are presented. One row is one user while one dot is 10s of video. Different colours present different augmentations' interactions and gaps present reading time.

	Reading	Default	Teaser	Animated frames
Average score (of 10 max)	2.9	4	3.41	3.09
Median reading time	3	4	3.5	3
STD	1.45	1.33	1.43	1.3

Table 5: Results of answering questions about the content of the comic book (10 questions).

User Preference

The questionnaires revealed that users did not consider the length of the digital content as too long for Default, Animated Frames and Teaser conditions. However, only in Teaser (38%) and Animated Frames condition (41%), participants highlighted that there could be more digital content. This was not expressed as intensely in Default condition (only 20% of participants agreed) with all content duplicated. For all interaction modes participants generally agree that added digital content complements the story rather than duplicates it (Animated Frames condition (90%), Teaser (79%) and Default (71%). Surprisingly, only 26% of participants marked the Default condition as a duplicator of the story showing that duplication was better accepted in school study than was anticipated based on the outcome of the real world study. Some participants admitted skipping reading due to the digital content: Default (17%), Animated Frames (9%) and Teaser (6%) condition. On contrary, some users expressed the preference for reading although they also watched the augmentations.

Comparing the Real World & Controlled User Study

The Default condition from the controlled study served to validate and interpret the results obtained in the real world study. The only difference between the two was the context (e.g. controlled environment of the school vs. uncontrolled 'in the wild').

Opened and Viewed Content. The controlled study demonstrates a much higher percent of opened content (92% vs. 53% 'in-the-wild') and longer video watching times (medians 7.4 minutes [82%] vs. 5.7 minutes [23%] 'in-the-wild').

Frequency of Content Consumption. In controlled study participants triggered a new video on average every 3.1 minutes (STD 1.24) vs. 2.1 minutes (STD 1.8) 'in-the-wild' meaning they spent more time on reading.

Reading Patterns. While the real world study revealed nine different interaction patterns, we observed only three basic patterns in the controlled study and no combination of them. Compared to 36% 'in the wild' in the controlled study only 15% ended in watching interaction pattern. It was observed that while some participants in the controlled study realised that the videos duplicate the story, they did not stop reading.

This all suggests that the context of the school study influenced users since they demonstrated more engagement with both the comic book and digital content.

7 DISCUSSION & CONCLUSION

Accessing the Content

The main audience of the comic book in our study is children and this research focuses exclusively on them. As such we cannot generalise the findings outside our target group since different audiences are likely to consume content differently. Despite this, the design factors and augmentation conditions are not limited to a particular audience.

The results of the real world study showed that duplicating the whole comic book with integrated video encouraged watching activity over reading in 36% of the cases (15% in the controlled condition). In 28% of the cases users stopped interacting with the digital medium. Both these interaction patterns defy the purpose of such hybrid medium. In order to mitigate these effects of duplication we designed Teaser and Animated Frames augmentations. We hypothesized that mitigating the effect is possible with: (i) careful placement of the digital content; (ii) careful spatial positioning of the content where context is maintained (e.g. we show only

video that directly relates to a particular frame); and (iii) appropriate frequency, and length of the content.

The design decisions had a positive influence on keeping readers engaged with printed medium since none of the participants in Animated Frames condition resorted to only watching the video. This conclusion is also supported by reported reading times. Animated Frames condition demonstrated longest reading time (6m 30s) which was only surpassed by reading only condition (7m 30s). On the other hand, duplication is known to have a positive effect on information retention [20] and pupils in Default condition scored highest in the questionnaire.

The controlled study also showed that consumer-ready technology we used caused issues. One of the most notable was keeping the augmented frames in camera view because of the short distance between the phone and the comic. While the researchers tried to help children move the comic book further away to capture the augmented content, children pulled it back for reading. We also observed them moving their chair backwards or even standing up to increase the distance between the comic book and the screen. Instead of becoming invisible, the technology became present-at-hand requiring conscious attention from the children [9]. In this respect, the NFC technology was more usable even if sometimes scanning NFC tags was unsuccessful in their first attempt. This observation is also supported by user engagement as none of the users' in Teaser condition stopped using the technology (3 [9%] in Default and 5 [17%] Animated Frames condition). Other observed technology issues include holding the phones in hands all the time affecting interaction with the book, and problems with headphone's wires being in the way.

While the initial training helped children to quickly grasp the technology, the comic book offered some false affordances. Children were observed to scan frames and pages that were not marked as augmented while some tried to read the whole comic book through the screen in order to not miss any of the augmented content. A notable frame with false affordance was a speech bubble with the music note (see Figure 1) that children thought was augmented even when previously told what marked the augmentation. The false affordance problem is not new to augmented books, showing the gap between expected interaction by designers and applied interaction by children [19]. Designers need to take the balance between constraints, real-world expectations, and previous knowledge the users will apply to interaction [6].

While designing digital augmentation for comic books, authors and designers need to find a balance between physical and digital medium. In order to achieve the holistic experience and equal engagement with both mediums (printed and digital) the findings derived from our studies indicate that the experience needs to be carefully designed by: (i) avoiding or reducing duplication especially when duplication means the reader gets no real benefit from engaging with both mediums, (ii) integrating augmented content only if it has high relevance to a particular frame in the comic book, (iii) using appropriate frequency, and length of the augmented content to maintain the interest in both digital and physical medium, and (iv) selecting the technology carefully as it still presents an interaction barrier (e.g. the access method).

Limitations

There are several limitations with our studies that need exploring in future work. First, in the real world study, we did not know the context of use of the comic and so assumed that pauses in between watching digital content were for reading. Asking parental reporting of use in the home would increase the confidence in these reports. Second, the classroom environment, although comfortable for the children, was still more controlled than relaxed reading at home. The children were aware of the researchers (and teachers) watching their progress and so were likely to be more engaged than if left on their own. Finally, as mentioned before, our studies focused solely on children. However, we still believe the study results provide clear insights into the use of the different interaction techniques.

Future Work

Beyond addressing the study limitations, there are several strands of future work we intend to pursue. First, we wish to further examine and study the design space to understand the impact of the remaining design factors not already tested. Second, we wish to confirm how our findings from AR comics generalise to other forms of digitally-augmented print media and other audiences. Finally, more formal studies of reading behaviour (such was with the use of eye-tracking) can characterise the reader's behaviour and provide better measures of engagement and retention with augmented content.

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