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Blended, Transmedia Learning: Investigating the Engagement of Elementary Students in a Cryptology and Cybersecurity Curriculum

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This convergent mixed method study investigates learner engagement during a blended, transmedia curriculum called CryptoComics, which is designed to teach 3rd-5th graders about cryptology and cybersecurity. Curriculum design is presented through the lens of four engagement facilitators: (1) anchoring the curriculum with a comic book, (2) blending digital and unplugged media, (3) supporting situational interest via a transmedia narrative, and (4) designing for social-cultural relevance. Latent profile analysis is used to develop profiles of learner engagement using quantitative indicators of cognitive and emotional engagement collected across 204 students at 13 implementation sites in the Eastern U.S. Qualitative indicators of engagement include teacher weekly check-ins submitted by 17 teachers working at the 13 implementation sites, student interviews, and classroom observations of 26 students participating in the curriculum at two local sites. Quantitative and qualitative results converge to suggest the majority of the students participating in the curriculum were highly engaged cognitively and emotionally. Qualitative data (1) suggest some third graders may be less cognitively engaged due to challenging content, (2) provide evidence for how the design of the blended, transmedia curriculum supported, and some cases hindered, engagement, (3) highlight the importance of transitions between blended learning components in facilitating engagement, and (4) uncover questions regarding one of the quantitative measures selected as an indicator of cognitive engagement.

Keywords: blended learning, transmedia, learner engagement, cryptology, cybersecurity, curriculum design

INTRODUCTION

It is estimated that cybercrime will cost the world $10.5 trillion annually by 2025, making it the world's third largest economy after the U.S. and China (Morgan, 2020). Cybercrime directed at children can result in financial (Chalk, 2022) and social emotional (Perez, 2018) consequences and such crimes have increased during the pandemic as youth spend more time learning, playing, and socializing online (FBI, 2020; Jargon, 2020). Children frequently exhibit poor cybersecurity judgement (Yan et al., 2021) and an inability to discuss strategies to keep themselves safe online (Macaulay et al., 2020), which increases their vulnerability to cyberattacks. Simultaneously, the U.S. is facing a severe shortage of cybersecurity professionals (CyberSeek, 2021) and the cybersecurity field suffers from a lack of diversity (U.S. Bureau of Labor Statistics, 2021).

CryptoComics is a blended, transmedia curriculum that responds to the aforementioned issues by introducing 3rd-5th graders to cryptology and cybersecurity and associated careers[1]. In this study, we use Halverson and Graham's (2019) framework for blended learning engagement to describe the design of CryptoComics and investigate learner engagement during curriculum implementation.

LITERATURE REVIEW

Blended learning is an evolving and dynamic concept but, at its core, it involves intentionally and meaningfully combining face-to-face and technology-mediated instruction to support engagement and learning (Graham, 2006). Numerous continuums and models for blended learning have been presented over the years. For example, Watson (2008) proposed a continuum between fully online and fully face-to-face experiences while Staker and Horn (2012) proposed several models for blended learning such as the rotation, flex, self-paced and enriched virtual models. Previous studies also embrace the term "blended learning classrooms" to describe the classroom environment in which students transition between digital and unplugged activities (Kundu et al., 2021). Indeed, there are "countless possible combinations" for blended learning (Halverson & Graham, 2019, p. 146). Transmedia storytelling (Bidarra & Rodrigues, 2018) is one strategy for blended learning that involves anchoring a curriculum in a story told across digital and unplugged media in such a way that learners enter a state of ultimate engagement or flow (Csíkszentmihályi, 2021). Instead of rotating through digital and face-to-face stations like many blended learning models (Staker & Horn, 2012), a blended, transmedia curriculum integrates digital and unplugged components that are anchored by a compelling story or narrative.

1 Cybersecurity involves protecting information online and cryptology, or the science of making and breaking secret codes, is considered the backbone of cybersecurity (Paar & Penzl, 2010).

As with all blended learning models, the goal of a blended, transmedia curriculum is learner engagement that leads to desired learning outcomes. Learner engagement is a multifaceted construct, and the most popular model includes three components – behavioral, cognitive and emotional engagement (Fredericks et al., 2004), however, other models have proposed social-behavioral engagement (Pekrun & Linnebrink-Garcia, 2012) and agentic engagement (Reeve & Tseng, 2011) to name a few. Although high learner engagement has been linked to a myriad of positive outcomes from higher student achievement and lower rates of delinquency to future career aspirations (Wang & Holcombe, 2010), research lacks a consistent definition of the construct and reliable measures that can be used across contexts (Fredericks et al., 2016; Sinatra et al., 2015).

The context of blended learning is one where studying engagement is further complicated as learners move within and across digital and unplugged spaces. Halverson and Graham (2019) developed a framework for blended learning engagement that draws on the work of Skinner et al. (2008) to differentiate between facilitators and indicators of blended learning engagement. Facilitators include instructional methods and other strategies designed to promote engagement in blended learning. Indicators are measurable factors related to cognitive and emotional engagement applicable to both digital and unplugged portions of blended environments.

After a robust, interdisciplinary review of empirical studies related to engagement, Halverson and Graham (2019) focused their framework on the "primacy of emotional and cognitive engagement as the most fundamental expressions of learner engagement" (p. 153). Behavioral engagement is not included as a separate component of the framework because behaviors are "recognized as outward displays of the mental and emotional energies that fuel learning" (p. 153). Cognitive engagement is defined as expending appropriate and useful mental energy in blended learning environments while emotional engagement encompasses positive and negative reactions to and within the blended environment. In keeping with the recommendation to explicitly defining engagement frameworks used within studies (Sinatra et al., 2015), we employ Halverson and Graham's (2019) work to frame this study.

Previous literature has not agreed on an effective measurement of engagement. Sinatra et al. (2015) highlight the importance of identifying where engagement measures fall on a continuum ranging from person-centered, person-in-context and context-oriented engagement measures. Person-centered engagement measures describe individual patterns of engagement often through the use of profiles while person-in-context measures involve strategies to understand engagement within a specific context through methods such as observations and self-reports. Context-oriented engagement measures highlight how classroom context, community and culture may facilitate or hinder engagement often through discourse analyses or critical analyses.

Given our unique context of a blended, transmedia curriculum, this study includes both person-centered and person-in-context engagement measures. Specifically, we seek to understand the ways in which engagement profiles (i.e. person-centered measures) converge or diverge with engagement as observed during the curriculum implementation (i.e. person-in-context measures). The following research questions guide this mixed methods study:

1. (Quantitative; person-centered measures) What engagement profiles exist among upper elementary students participating in a blended, transmedia curriculum about cryptology and cybersecurity?
2. (Qualitative; person-in-context measures) What types of engagement are evident through observations of and teacher feedback about a blended, transmedia curriculum?
3. (Mixed) In what ways does quantitative and qualitative evidence of engagement converge or diverge during a blended, transmedia curriculum?

CRYPTOCOMICS' DESIGN AND FACILITATORS OF BLENDED LEARNING ENGAGEMENT

CryptoComics is a blended, transmedia curriculum designed to introduce 3rd-5th graders to cryptology and cybersecurity and associated careers. It is designed with the goal of engaging all learners but employs strategies to explicitly engage groups underrepresented in cybersecurity careers such as those who are African-American and female (Dawson et al., 2022). The curriculum includes three interrelated components: (1) a digital comic book, (2) a series of web-based games, simulations and activities and (3) unplugged activities. The blended, transmedia format leverages the strengths of digital and unplugged media and includes careful and intentional transitions across media.

Halverson and Graham's (2019) model of blended learning engagement defines facilitators as instructional methods and other strategies built into blended learning environments to support engagement. Numerous strategies were employed to facilitate engagement in CryptoComics including (1) anchoring the curriculum with a comic book, (2) blending digital and unplugged media, (3) supporting situational interest via a transmedia narrative and (4) designing for social-cultural relevance.

Anchoring the Curriculum with a Comic Book

Anchored instruction involves situating learning in such a way that it feels authentic and gives context to the content to be learned (The Cognition and Technology Group at Vanderbilt, 1990) and stories can serve as effective anchors (The Cognition and Technology Group at Vanderbilt, 1992).

In particular, comic books are effective at anchoring curriculum in engaging ways (Gavigan, 2014), especially when the content involves unfamiliar STEM content (Ganesh, 2013; Maryani & Amalia, 2018) such as cryptology and cybersecurity.

CryptoComics is anchored by a digital comic book that allows learners to follow the cyber adventures of four young characters. The story begins when Akila, Bai and Carly are sucked into a cyberworld after using a tablet to take a picture of a curio that had belonged to Akila's grandmother (Figure 1). Akila's little brother, Jabari, communicates with the girls through the tablet as they crack codes, solve puzzles and learn the history of code breaking and making to escape the cyberworld. The characters travel through space and time and visit places like Ancient Greece and the Government Code and Cypher School (GCCS) where they meet important historical figures like Alan Turing and learn about less visible contributions to cryptology such as the WAVES (Women Accepted for Volunteer Emergency Service) program where women, like Akila's grandmother, worked around the clock to break codes during World War II.

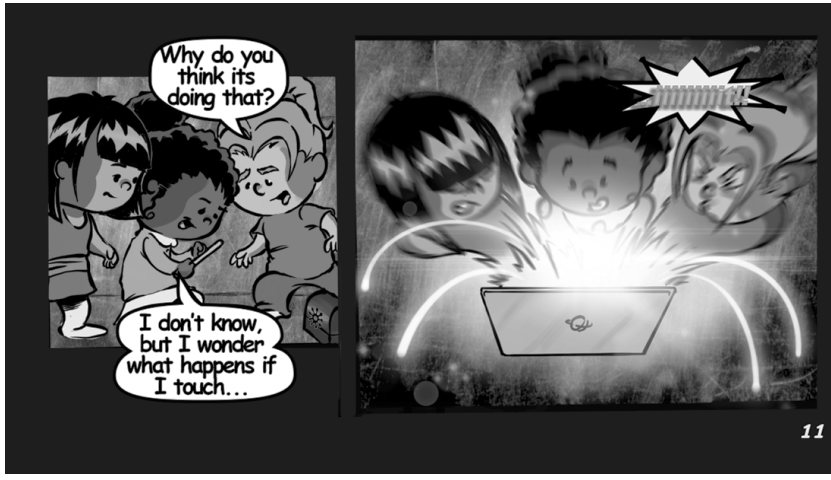

Figure 1. A comic book page - Akila, Bai and Carly are sucked into a cyberworld.

Blending Digital and Unplugged Media

Within blended learning environments transmedia narratives engage learners within and across digital and unplugged activities (Bidarra & Rodrigues, 2018). What happens in the comic book is intentionally connected to the web-based and unplugged activities. For example, the girls' cyberadventures take them to Africa where they learn about the Adinkra culture, to

the Chihuahuan desert where they learn about Navajo culture, and to Ancient China where they learn about old Chinese letters. As the girls in the comic book learn that wisdom is represented by different symbols across these cultures, learners are also participating in unplugged and digital activities to reinforce a basic concept of cryptology - cultures have different symbols for the same words and ideas. Digital activities include encoding and decoding messages using Ancient Chinese characters and unplugged activities including making stamps of Adinkra symbols and creating invisible messages with them (Figure 2).

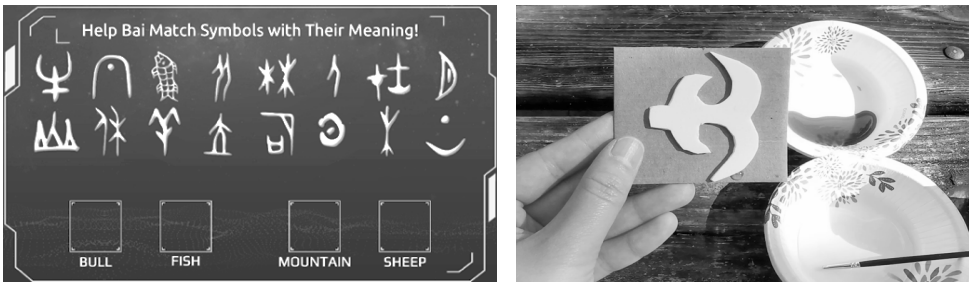

Figure 2. Example of digital and unplugged activities.

Note: Digital activity - decoding Ancient Chinese symbols (left) and unplugged activities – making Adinkra stamps and invisible ink (right).

Supporting Situational Interest via a Transmedia Narrative

CryptoComics is designed to spark situational interest or a scenario where learners are engaged and interested in curriculum content and activities (Hidi & Harackiewicz, 2000). While situational interest is context-dependent, it can be a precursor to more sustained, individual interest in a topic or activity (Renninger & Hidi, 2016). Situational interest is facilitated by the transmedia narrative told through the comic book. As the characters experience challenges in the comic book, learners explore similar situations in the digital and unplugged components of the curriculum. For example, the comic book characters travel back in time to the Government Code and Cypher School and meet a WAVES woman named Dorothy who turns out to be Akila's grandmother. Dorothy introduces the girls to Alan Turing who is trying to open the briefcase of a recently detained spy using a letter found in his jacket (Figure 3). At this point, the students stop reading the comic book and work on a digital simulation where they use the spy's letter to try to figure out how to open the briefcase. They then have a whole class discussion and learn the way they used the spy's personal information to figure out his password is a technique commonly used by hackers called social

engineering (Figure 4). Students then participate in an unplugged activity called “Phishing for Information” that teaches them to distinguish between personal and private information (Figure 5). Finally, students return to the comic book to see what happened with the girls.

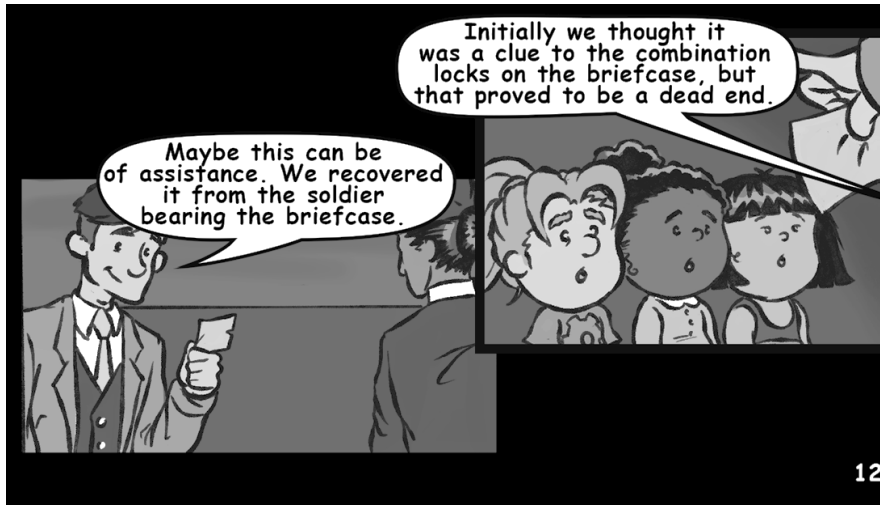

Figure 3. Comic book page - Alan Turing found a note from the jacket pocket of a spy.

Figure 4. Social engineering simulation – use the spy’s note to find password.

Figure 5. Unplugged activity – Phishing for Information.

Designing for Social-Cultural Relevance

CryptoComics employs several strategies to support social-cultural relevance (Gay, 2013). First, the comic book uses an anime style design that resonates with elementary learners (Wusylko et al., 2022). Second, the main characters have different backgrounds, personalities and strengths which allows students to connect most closely with characters most like them (Wusylko et al., in press; Taylor, 2010; Figure 6). The curriculum also includes diverse role models to support career awareness. For example, students meet the cyber security researcher who identified a major flaw in iPhone's iMessage™ application that allows for remote hacking of an iPhone™ (Silvanovich, 2019).

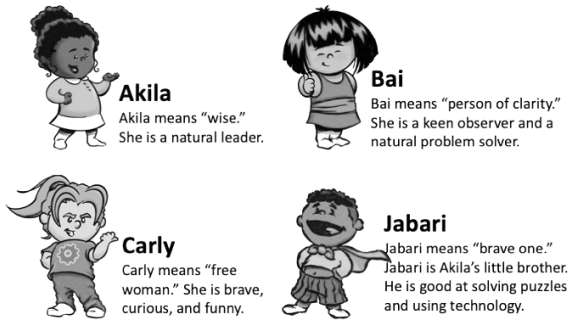

Figure 6. Comic book characters.

RESEARCH DESIGN

Mixed methods research leverages the strengths of quantitative and qualitative research to more thoroughly explore and understand a research phenomenon (Creswell & Plano Clark, 2017). A convergent mixed methods design was used to quantitatively identify engagement profiles of learners participating in this blended, transmedia curriculum and qualitatively explore in what ways, if any, these profiles converged with observations of a diverse subset of learners participating in the curriculum and with teacher reports of curriculum activity. Integrating quantitative and qualitative measures provides a richer understanding of engagement within this blended, transmedia curriculum.

Participants

This mixed methods study uses person-centered data from 204 learners in 13 afterschool programs in the Eastern U.S., and person-in-context measures from 26 learners from two local sites where observations of curriculum implementation were possible. Learners in the person-centered data are in the 3rd to 6th grades, with a mean age of 9.31 years old (SD = 0.98). Forty-seven learners are boys;153 are girls; and four students prefer not to report their gender. In regarding student race, 25.49% of learners identify themselves as White; 53.92% are Black/African Americans; and 20.59% of learners report other races. It is noted that this curriculum targets underrepresented learners in STEM, especially girls and African American students. Therefore, our data is representative of our population. Detailed student demographic information is included in Table 1.

The 26 observed students are from two local programs that are in two public elementary schools. Although the sample of observed students was limited by geography, the two local sites featured a range of students – one program serves only African American students, and the other program serves students with learning differences. The observed learners include 14 girls and 12 boys whose age ranges from 8 to 12 years old. Seventeen of them are African American, five are white, and two - American Indian or Alaska Native.

Table 1
Student demographic information

		All Programs		Local Programs	
		N	%	N	%
Sex	Girls	153	75	14	53.85
	Boys	47	23.04	12	46.15
	I'd rather not say	4	1.96	0	0.00
Race	American Indian or Alaska Native	9	4.41	2	7.69
	Asian	4	1.96	0	0.00
	Black/African American	110	53.92	17	65.38
	Native Hawaiian or Other Pacific Islander	3	1.47	0	0.00
	White	52	25.49	5	19.23
	Mixed	14	6.86	2	7.69
	Other/ I'd rather not say	12	5.88	0	0.00
Age	8	40	19.61	5	19.23
	9	86	42.16	6	23.08
	10	49	24.02	4	15.38
	11	21	10.29	9	34.62
	12	3	1.47	2	7.69
	I'd rather not say	5	4.39	0	0.00
Grade	3rd	46	22.55	7	26.92
	4th	105	51.47	5	19.23
	5th	46	22.55	13	50.00
	6th	2	0.98	1	3.85
	I'd rather not say	5	2.45	0	0.00

DATA COLLECTION AND ANALYSIS

Quantitative Data Collection

Aligning with Halverson and Graham's (2019) framework for blended learning engagement, we used indicators associated with cognitive and emotional engagement to derive profiles of learner engagement during the blended, transmedia curriculum (Table 2).

Cognitive engagement

In order to have a comprehensive understanding of learners' cognitive engagement throughout the curriculum, we collected log data during two web-based activities (one at the beginning and one near the end of the curriculum) and student learning outcome at the end of the curriculum implementation.

One activity called Decoder in Training (Figure 2) is a digital activity in the first module of the curriculum. In this activity, students practice decoding ancient Chinese pictograms that picturize the objects and phenomena they represent. Sixteen Chinese pictograms are presented at the top of the game interface and four boxes with symbol meaning are located at the bottom of the interface. Learners successfully decode a symbol by dragging it to a box to correctly match the symbol with its meaning.

The second activity called Number Ciphers (Figure 7) is in the fourth module of the curriculum. The interface of this activity includes 3 areas. The top area shows the instruction with a given key. The bottom left area is a number cipher wheel. The bottom right area has a grid that provides numbers to decode in the first row of a grid. Learners use the number cipher wheel to decode a series of numbers into English words. For example, to decode number 17 in the ciphertext, learners drag the corresponding letter in the cipher wheel (i.e., "p") to the cell below ciphertext 17 in the grid.

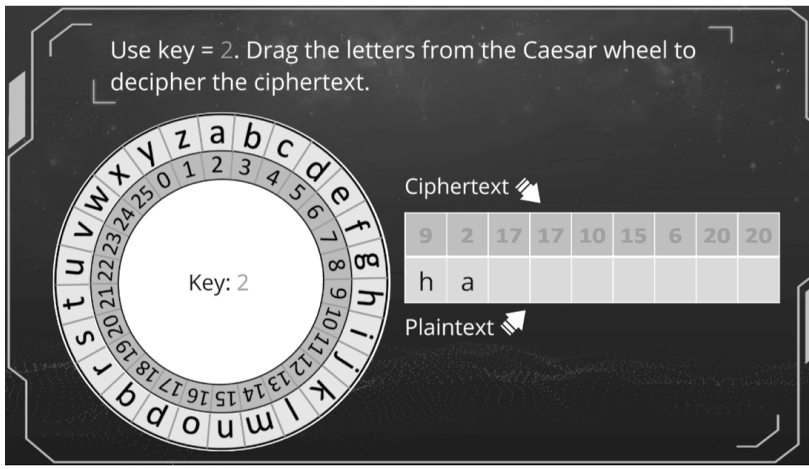

Figure 7. A screenshot of the Number Cipher activity.

In both learning activities, learners must correctly complete all symbols or numbers on a screen to proceed to the next screen. Therefore, learners are allowed make multiple attempts until they correctly decode a symbol or a number. The app records the number of errors a learner makes for each

symbol/number. Therefore, we generated two mean error variables reflecting learners' cognitive engagement during the learning process: (1) MeanError1 is the average number of errors a student makes to correctly decode a symbol in the activity Decoder in Training; (2) MeanError2 is the average number of errors a student makes to correctly decode a number in Number Cipher activity. We hypothesize that lower mean error values indicate "mental energy focused on learning" (Halverson & Graham, 2019, p. 154) and equate with higher cognitive engagement.

After learners finished all the six modules of the curriculum, learning outcome was measured using a knowledge of cryptology and cybersecurity assessment generated by the research team. This assessment contains 13 items and measures learners' understanding of the key concepts in the curriculum. The development of this instrument was guided by the framework of Standards for Educational and Psychological Testing (American Educational Research Associate et al., 2014) to provide evidence of content validity. This assessment was also piloted in two previous studies and demonstrated validity based on student response processes. To ensure consistency in test administration, the assessment was administered using Qualtrics, a digital survey platform. Each item also contains an audio file, so students can listen to the items if they prefer. We hypothesize that higher scores on this learning assessment equates to higher cognitive engagement.

Emotional engagement

We measured three variables associated with emotional engagement: (1) perceived identity in cryptology and cybersecurity, (2) learner perception of the comic book, and (3) perceived usability of the digital curriculum components.

A learner's STEM identity is shaped by one's engagement and experience in various STEM activities, especially informal STEM education experience in a learner's childhood (Dou et al., 2019). In this study, we used learners' perceived identity in cryptology and cybersecurity as a proxy for emotional engagement because a positive perception of identity will likely result in indicators of positive emotional engagement such as increased interest in, confidence with and enjoyment of the curriculum (Halverson & Graham, 2019). A cryptology and cybersecurity identity scale was adapted from the engineering career subscale of Engineering Identity Development Scale developed and validated by Capobianco and colleagues (EIDS; Capobianco et al., 2009; 2012). The subscale contains 11 items with each item using a 1 to 3 points Likert scale. Students took the survey after the knowledge of cryptology and cybersecurity assessment when they finished the curriculum. The survey scores in current study revealed acceptable reliability (Cronbach's *alpha* = 0.71).

Table 2
Measures and variables for cognitive and emotional engagement

Dimension of Blended Learning Engagement	Measure/Activity	Variable
Cognitive Engagement	Knowledge in cryptology and cybersecurity assessment	Knowledge – total score
	Decoder in Training	MeanError1 - average number of errors a student makes in decoding a symbol
	Number Cipher	MeanError2 - average number of errors a student makes in decoding a number
Emotional Engagement	Cryptology and cybersecurity identity scale	Identity – total score of student response to the scale
	Adapted SUS for Children	Usability– total score
	Comic book perception survey	ComicPercept – total score

The second emotional engagement index is the learner perceived usability of the app. The definition of usability emphasizes three dimensions: effectiveness, efficiency, and satisfaction (International Organization for Standardization, 1998). Associated with emotional engagement, the third dimension "satisfaction" is commonly measured as perceived usability (Lewis, 2018). Perceived usability influences the learner's attitudes towards the technology as well as their learning experiences (Vlachogianni & Tselios, 2021). We used a version of the System Usability Scale (SUS; Brooke, 1996) adapted for 7- to 11-year-old children (Putman et al., 2020). The adapted SUS added additional three items to measure enjoyment, which also aligns with emotional engagement. However, in a previous pilot study, we found that our participants had difficulty in responding to the negatively worded items, which threated the test validity based on student response processes and resulted low internal consistency of the test scores. Therefore, in this study, we selected the 8 positively worded items from the adapted SUS. Learners filled out this survey after the comic book perception survey. The test scores revealed acceptable internal consistency (Cronbach's *alpha* = 0.73).

Another significant component of our curriculum is the digital comic book, which was used as a transmedia narrative to anchor the instruction and situate learners in a problem-solving learning context with the aim to support situational interest. Therefore, the research team designed a survey

to understand student perception about the comic book. This survey contains eight items that ask learners about their overall impression, visual design, character design, and story design of the comic book as well as perceived learning using the comic book. A five-point Likert scale ranging from 1 to 5 is employed for each item. A learner's comic book perception was quantified as the sum of the learner's response of all items. This survey was administered immediately after the identity survey described above. The comic book perception scores have high internal consistency (Cronbach's *alpha* = 0.91).

Quantitative Data Analysis

With the aim to explore student engagement profiles, we employed latent profile analysis (LPA) to explore data generated from the person-centered measures. LAP is a type of mixture model that seeks to identify unobserved subgroups, or profiles, based on certain variables (Bauer, 2022). Like other mixture models, LPA can be used in exploratory and confirmatory data analyses (Finch & Bronk, 2011). In the previous studies, LPA was employed to explore the engagement profiles of elementary and middle school students (Bae & DeBusk-Lane, 2019; Bae et al., 2020). In this exploratory study, we employ LPA to identify learner engagement profiles based on the aforementioned variables related to cognitive and emotional engagement. We estimated 2 to 7 profiles and compared model fit. At the same time, for each number of estimated profiles, we set variable variances to be equal and covariances to be zero. To determine the optimal number of profiles, we applied a widely accepted multiple criteria decision-making approach - Analytic Hierarchy Process (AHP; Akogul & Erisoglu, 2017) and used multiple information criteria, including Akaike's Information Criterion (AIC), Approximate Weight of Evidence (AWE), Bayesian Information Criterion (BIC), Classification Likelihood Criterion (CLC), and Kullback Information Criterion (KIC). Entropy value was examined to evaluate the accuracy of classification. Entropy values range from 0 to 1, and values closer to 1 indicates higher accuracy. Data analysis was conducted using tidyLPA package (Rosenberg et al., 2019) in RStudio.

Qualitative Data Collection

Two researchers observed each time CryptoComics was implemented. Implementation times varied from 45 – 90 minutes depending on class schedules and full implementation of the curriculum took 8 weeks at Site A and 9 weeks at Site B. In addition, we collected weekly check-in surveys from all 17 teachers implementing the curriculum and conducted interviews with students at local sites.

Classroom observations

An observation protocol was created and tested for usability and inter-rater agreement during a pilot implementation of the curriculum. The observation protocol included ratings for cognitive and emotional engagement aligned with Halverson and Graham's (2019) blended learning framework. Considering the class as a whole, observers rated engagement on a 4-point scale from No engagement to Very Engaged. Indicators of cognitive engagement included attention, focus/on-task, following directions, using vocabulary and discussing content from the curriculum, responding to questions and asking relevant questions. Observers also rated how well curriculum objectives were met during each session. Indicators of emotional engagement included demonstrating interest in the curriculum and exhibiting a positive attitude toward it.

Observers rated engagement indicators for each portion of the curriculum which enabled us to look at engagement as a whole, by cognitive and emotional engagement and by the three curricular components (comic book, digital and unplugged). For example, the observation protocol for the first module included headings such as Comic Book Reading (pages 1-12), Unplugged Adinkra Stamp Activity, and Digital Ancient Chinese Decoder in Training. Each heading was followed by the aforementioned indicators of engagement. In addition, observers took descriptive and reflective field notes (Bogdan & Biklen, 1997) to provide a richer perspective on engagement.

Teacher weekly check-ins

Observations were possible only in local schools for logistical reasons. However, 17 teachers (3 local and 13 non-local) completed 95 weekly check-ins throughout their curriculum implementations. These weekly check-ins were primarily designed to help researchers support the teachers. However, one item asked the teachers to rate how interested their students were in the topics covered that week on a 5-point scale from 5-Very Interested to 1-Very Disinterested. In addition, there were open-ended questions where teachers could provide general comments and reflection about curriculum implementation each week. Halverson and Graham (2019) discuss interest as an important indicator of engagement and some of the general comments also provided insights on engagement.

Student interviews

In another study, the research team explored student perception of the comic book (Wusylko et al., in press) by conducting semi-structured interviews with students. The interview questions probed if and how the comic book help student learning and how the comic book is connected with other

components of the curriculum, which is related to student cognitive engagement. Other questions asked about if students liked the comic book and why, which is associated with emotional engagement. Three students from Site 1 and four students from Site 2 voluntarily participated in the interview after the teachers completed the curriculum implementation.

Qualitative Data Analysis

Data from classroom observations were analyzed in three phases. First, engagement ratings were organized by curricular topic and ratings from the two observers were averaged. Averaged results were compiled by cognitive engagement, emotional engagement and overall engagement. Cognitive and emotional engagement was also compiled by curricular component (i.e. comic book, digital and unplugged) for the two observation sites. Second, field notes from the observations and data from teacher weekly check-ins and student interviews were coded using a priori coding for positive and negative evidence of cognitive and emotional engagement. Another round of coding followed to further clarify the engagement codes. For example, the subcode "retention" was matched with some evidence of positive cognitive engagement when students remembered concepts previously learned in the curriculum. Finally, the codes and engagement ratings were merged into categories representing qualitative results (Saldaña, 2021). Strategies employed to increase the rigor of this qualitative analysis included keeping an audit trail, triangulation of two data source, peer debriefing and prolonged engagement via multiple observations (Lincoln & Guba, 1985).

Data Integration

Quantitative and qualitative results were merged using a side-by-side comparison that enabled us to look for instances of convergence and divergence in the datasets (Creswell & Plano Clark, 2017). The integrated data was then organized and presented as themes in narrative form to answer the final research question (Creswell & Plano Clark, 2017).

RESULTS

RQ1: What engagement profiles exist among upper elementary students participating in a blended, transmedia curriculum about cryptology and cybersecurity?

Descriptive statistics and bivariate correlations are presented in Table 3. All the variables were normally distributed, except average number of errors in the Number Cipher activity (MeanError2). However, LPA only assumes normal distribution within profiles. Therefore, the high skewness

and kurtosis did not impact the results of LPA. The cognitive engagement variables were not correlated, but significant positive correlations were observed among the emotional engagement variables. In addition, we found that the knowledge of cryptology and cybersecurity score is significantly correlated with the cryptology and cybersecurity identity score and comic book perception score. We explored learner engagement profiles for cognitive engagement, emotional engagement, and global engagement.

Table 3
Descriptive statistics and bivariate correlations

	Mean	SD	Skewness	Kurtosis	1	2	3	4	5
1. Knowledge	7.46	2.39	-0.19	-0.48	-				
2. ErrorDecoder	1.44	1.24	1.17	1.95	-0.11	-			
3. ErrorNumCph	0.42	0.99	4.27	19.32	-0.18	0.05	-		
4. Identity	27.24	3.50	-0.61	0.76	0.29*	0.08	0.14	-	
5. Usability	21.86	5.65	-0.53	0.13	0.14	-0.14	-0.13	0.42*	-
6. ComicPercept	32.27	7.25	-1.02	0.74	0.23*	-0.02	0.03	0.38*	0.57*

Cognitive Engagement Profiles

Latent profile models containing two to seven profiles were fit into data from cognitive engagement variables (knowledge assessment score, mean error in the activity Decoder in Training, and mean error in the Number Cipher activity). Results of the model fit indices are shown in Table 4. An AHP suggested that the 2-profile solution fit the best among the 6 solutions, with low BIC and AWE values. The Entropy value of the 2-profile model was .95, suggesting good accuracy in classifying learners into the two profiles. The p value of bootstrap likelihood ratio test (BLRT) was .01. Seventy-five students were classified into Profile 1 and 129 students were in Profile 2. As shown in Figure 8, students in Profile 1 scored lower in the knowledge assessment at the end of the curriculum, while they made comparatively more errors in the two digital activities. Therefore, Profile 1 was labeled as “low cognitive engagement profile” and profile 2 was “high cognitive engagement profile.” In addition, the visualization also indicated that there were not clear distinctions between the two clusters for ErrorDecoder and ErrorNumCph variables.

Emotional Engagement Profiles

To understand students' emotional engagement profiles, we entered the scores of cryptology and cybersecurity identity scale, comic book perception survey, and adapted SUS for Children into the latent profile models with two to seven profiles. Model fit indices are included in Table 4. Results of an analytic hierarchy process (AHP) indicated that 2-profile model appropriately fitted our data. The model fit indices also demonstrated best model fit of 2-profile model according to AWE, BIC, and KIC. The p value of BLRT was .01. Entropy value was .83, indicating good classification accuracy. Profile 1 included 66 students, and 138 students were classified into Profile 2. The visualization of the two emotional engagement profiles is presented in Figure 8. Learners in Profile 1 had lower scores across the three measures. Thus, Profile 1 is labeled as "low emotional engagement profile," and Profile 2 is labeled as "high emotional engagement profile."

Table 4

Model fit indices for the 2- to 7-class solutions for cognitive and emotional engagement profiles

	Classes	AIC	AWE	BIC	CLC	KIC	Entropy
Cognitive engagement profiles	2	1675.47	1789.93	1708.65	1657.37	1688.47	0.95
	3	1661.53	1823.02	1707.98	1634.94	1678.53	0.70
	4	1654.53	1862.48	1714.26	1620.04	1675.53	0.75
	5	1639.60	1894.07	1712.60	1597.13	1664.60	0.76
	6	1670.34	1971.58	1756.61	1619.64	1699.34	0.65
	7	1636.40	1983.94	1735.94	1577.94	1669.40	0.77
Emotional engagement profiles	2	1611.54	1726.24	1644.72	1593.19	1624.54	0.83
	3	1616.77	1778.54	1663.22	1589.90	1633.77	0.57
	4	1625.03	1833.66	1684.75	1589.84	1646.03	0.41
	5	1619.07	1873.92	1692.07	1576.21	1644.07	0.57
	6	1611.09	1912.17	1697.37	1560.56	1640.09	0.73
	7	1617.87	1965.62	1717.42	1559.21	1650.87	0.67

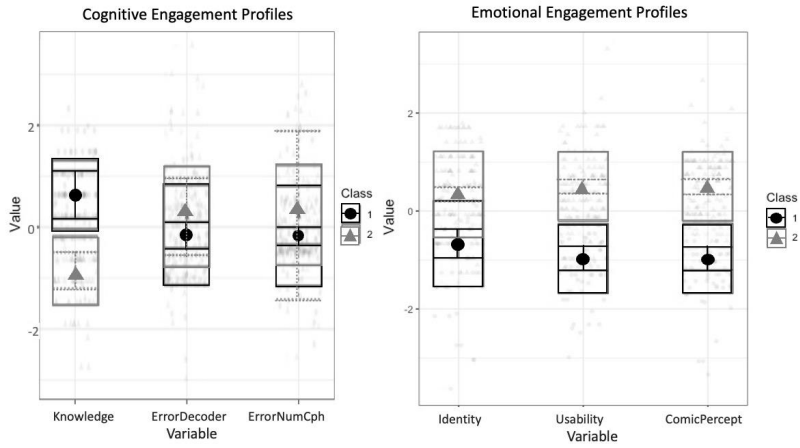

Figure 8. Visualizations of cognitive (left) and emotional (right) engagement profiles.

Global Engagement Profiles

We first conducted a chi-square test to examine the association between previously generated cognitive and emotional engagement profiles. The result was not statistically significant. Further, we explored the global engagement profile using four variables: knowledge assessment score, identity score, perceived usability score, and comic book perception score. We chose these four scores for two reasons. First, all four scores were measured at the end of the curriculum implementation. Since we did not collect any emotional engagement data during the activities, we used the four scores to keep measurement time consistent. Second, the two mean error variables had non-significant correlations with the other variables. Entering them into the model would result a high number of profiles that are hard to interpret. Similarly, we found that the AHP and fit indices both recommended a 2-profile model (Table 5). The Entropy value was .81, and p value for BLRT was .01. Profile 1 included 50 students, and profile 2 included 154. According to Figure 9, Profile 1 is labeled as “low global engagement profile”, and Profile 2 is “high global engagement profile.”

Table 5

Model fit indices for the 2- to 7-class solutions for the global engagement profiles

Classes	AIC	AWE	BIC	CLC	KIC	Entropy
2	2203.45	2353.11	2246.58	2179.06	2219.45	0.81
3	2197.53	2405.41	2257.26	2163.10	2218.53	0.79
4	2195.78	2462.06	2272.09	2151.13	2221.78	0.68
5	2196.82	2521.26	2289.72	2142.19	2227.82	0.69
6	2201.06	2583.73	2310.55	2136.38	2237.06	0.66
7	2211.13	2652.11	2337.22	2136.34	2252.13	0.60

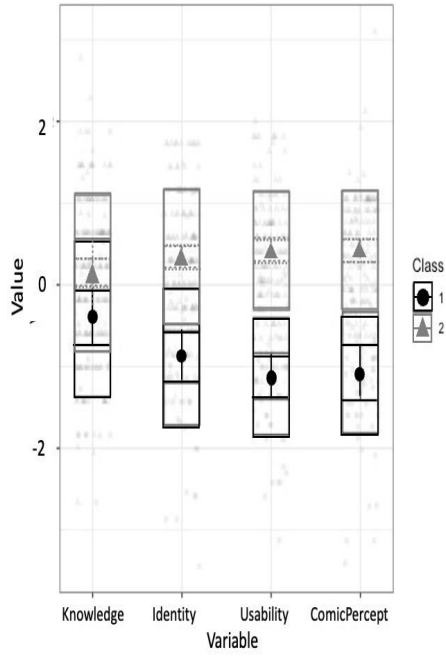

Figure 9. Visualization of global engagement profiles.

RQ2: What types of engagement are evident through observations of and teacher feedback about a blended, transmedia curriculum?

Qualitative engagement ratings of classes implementing CryptoComics at two local sites were transformed into numeric form for ease of presentation (Creswell & Plano Clark, 2017). Cognitive and emotional engagement ratings were consistent and high at both sites and across curricular components (See Table 6 and Table 7).

Table 6
Overall Engagement Ratings

	Cognitive	Emotional
Site 1	3.60	3.55
Site 2	3.82	3.73

Note: 4 – Very Engaged, 3 – Most Engaged, 2 – Barely Engaged, 1 – Not Engaged at All.

Table 7
Engagement ratings Rating by Curricular Component

		Cognitive	Emotional
Comic Book	Site 1	3.67	3.59
	Site 2	3.69	3.70
Digital	Site 1	3.83	3.64
	Site 2	3.92	3.83
Unplugged	Site 1	3.66	3.58
	Site 2	3.83	3.69

Note: 4 – Very Engaged, 3 – Most Engaged, 2 – Barely Engaged, 1 – Not Engaged at All.

Classroom observations, weekly check-ins and student interviews supported the descriptive qualitative data in that most evidence pointed toward positive cognitive and emotional engagement although negative engagement was present to a lesser degree as well.

Positive Cognitive Engagement

Most evidence of positive cognitive engagement related to students (1) making connections between curricular topics and their experiences, (2) retaining curricular information and (3) demonstrating positive cognitive engagement during transitions across the various blended components.

Students *made connections between curricular topics and their experiences* in a variety of ways. For example, a teacher reported students' excitement at realizing that the morphemes they had learned about in reading class related to decoding (Teacher weekly check-in) while another teacher reported that "the students were very engaged and really began to talk about the correlation with coding" when discussing cryptology as the science of making and breaking secret codes (Teacher weekly check-in). Classroom observation data revealed students being "excited to share their stories" related to hacking with one student sharing that his PlayStation was hacked and another sharing that his Mom's Instagram account was hacked (Site 1, Observer 2). Students also made connections between slang (secret language) and their communications with each other by sharing different slang words they use regularly (Site 1, Observer 1).

Students *retained curricular information* to a degree that surprised many of the teachers. The final module involves students reviewing curricular content via games and puzzles that lead them to identify the person who hacked Akila's tablet and set off the girls' cyberadventure. One teacher commented in her final weekly check-in that she "was actually really surprised that the students did such a good job remembering everything for the review at the end." Another teacher affirmed this by expressing surprise by "how quickly we went through the last chapter. They remembered so much!" (Teacher weekly check-in). Similar sentiments were expressed throughout classroom observations and weekly check-ins with reports of students retaining information about vocabulary words such as hogan (Site 1, Observer 1), cryptology (Site 1, Observer 1), cryptologists (Site 2, Observer 2), plaintext (Site 1, Observer 2) and ciphertext (Site 1, Observer 2). Students also retained information about the differences between transposition and substitution ciphers and were able to correctly identify and use examples of each (Site 1, Observer 1; Site 2, Observer 2). Students were also "able to retell the [comic book] story with plenty of details" (Site 1, Observer 2).

Students also *demonstrated positive cognitive engagement during transitions* across the various blended components. One teacher reported in her weekly check-in that "the students were able to understand route ciphers and went from the paper activity to the web activity with ease. I was pleasantly surprised" while another teacher reported "I continue to be impressed with the student's ability to grasp the concepts and apply them to all the

activities digital and unplugged." After learning about the symbols for wisdom in three different cultures and participating in multiple unplugged and digital activities, one student exclaimed "Oh! There's that symbol again" when it showed up in the comic book again (Site 2, Observer 1). Students also began moving among modalities on their own with one teacher reporting in his weekly check-in that students "were so excited! When they got to the Chinese symbols they wanted to complete the activity without seeing the words on the screen. They began to write them down in their notebooks to make it more difficult" and one observer noted that students referenced paper copies of their codebook when working on digital activities (Site 2, Observer 2).

In addition, we found that the comic book supported student cognitive engagement in two ways: providing problem-solving scenarios and helping seamless transition between digital and unplugged activities. In the interviews, multiple students reported that the comic book helped their understanding in learning the curriculum, because the comic book provided them problems to solve and clues to solve the problems, so that they understood the goal of the activities and how to approach the problems. A student told us, "It really did help us very good in understanding things… It gives you a puzzle to solve and it makes me work, too." When students were asked about how the comic book connected the other activities, many students provided specific and detailed examples about the problems the comic book gave and how they solved the problems by participating in the web-base and unplugged activities. A boy said, "I feel like it's [the comic book and unplugged activities are] like the same thing, but on the paper [unplugged activity], it just like it explains it more." Another girl described the comic book plot - the characters went to Ancient China - and what she did to complete the web-based ancient Chinese symbol activity. Thus, the comic book supported their understanding of the activities and helped with transitions among the three curricular components.

Positive Emotional Engagement

In some cases, positive emotional engagement overlapped with positive cognitive engagement with one teacher reporting in her weekly check-in that "Chapter 6 was the most challenging chapter, but it was also the most likable chapter. The students enjoyed Hack the Hacker activities and Crypt-a-thon." Positive emotional engagement was also strong during the comic book portion of the curriculum with students eager to participate whether the teacher asked for volunteers to read out loud or instructed the students to silently read (Site 1, Observer 1). Teacher weekly check-ins and observations at both sites also suggest learners connected with the characters and were highly engaged in discussions about which characters with which they most related.

The strongest evidence of positive emotional engagement shows that students did not want the curriculum to end as evidenced in these quotes from teacher weekly check-ins:

- "If you ask the students, we don't have enough time. They wished that they could continue working."
- "How sad the girls were that the curriculum had ended."
- "They absolutely loves the zig zag ciphers. They had a great time creating their own and didn't want to stop."
- "How upset the girls were that the program was finished."

Similar sentiments were seen during classroom observations with one student asking her teacher "Ms XX, can we add a day?" (Site 2, Observer 1) and other students saying "I don't want to end CryptoComics. It's so fun!" and "NOOO. I like it!" (Site 2, Observer 2). This student-teacher dialogue further supports positive emotional engagement:

- Student: "Can you send me to CryptoComics?"
- Teacher: "You are already in CryptoComics."
- Student: "No, I want to work in CryptoComics." (Site 2, Observer 2).

Positive emotional engagement was even evident in students often not engaged: "The students were very engaged with the plugged and unplugged activities. This population will tend to shut down or feel discouraged if they think that they are having to do anything with reading, but today, they loved this experience." (Teacher weekly check-in). Another teacher referring to students who are often not engaged noted that "I am continually surprised by the students' willingness and desire to read and continue to want to solve all the puzzles." (Teacher weekly check-in).

The comic book increased student emotional engagement using interesting and exciting stories. Students were invested in helping the characters escape their predicaments by solving puzzles and mysteries presented in the comic book during the digital and unplugged components. One student stated: "I like how they [characters] give codes and mystery … kind of like a solve problem thing." During an interview, a student even requested, "Can it [the comic book story] have expansions?" and another student said, "I really want to continue it." Many students told us they loved reading comic book because of the fact-based fictional adventurous story. A girl said, "I like how they went on this cool adventure about how to decod[e] and about the history of the grandma and how they figured out what happened [with] the WAVES." This girl was referencing the history told in the comic book about a group of female cryptologists (WAVES) served the US Navy during WWII. Other students used words "puzzles," "adventures," and "mystery" to explain why this comic book was exciting for them.

Negative Cognitive Engagement

While not as prevalent as the evidence for positive cognitive engagement, evidence for negative cognitive engagement existed. Certain activities appear to have promoted negative cognitive engagement. For example, classroom observations and teacher weekly check-ins suggest that zigzag ciphers were challenging for students. What one teacher reported in her weekly check-in exemplifies the challenge: "Getting students to understand how to solve and create Zigzag Ciphers by hand when having to put the first group of letters in the first row and the second group of letters in the second row and then doing the zig zag formation. All of my students were confused ([some] more than others), but once I explained a few more times they all understood." Another teacher suggested a remedy to the frustrations students experienced: "Over half the kids struggled with the Zigzag Cipher when it was on paper. I think having them drag the letters into the boxes instead of just tracing the path [in the digital activity] could be a helpful in between."

This teachers' suggestion relates to where negative cognitive engagement was most prevalent – when transitions between digital and unplugged activities were not seamless. Another example relates to the Caesar Wheel which was mentioned by several teachers as an area of negative cognitive engagement for some. A teacher reported that he was "was surprised with how many students struggled with the Caesar Wheel, many did not understand which to use plaintext or cipher text. Some students rushed through the app and guess[ed] a lot which made the unplugged activities slightly more difficult."

Negative cognitive engagement also appeared to be more prevalent among 3rd graders than older participants with 3rd graders have more difficulty with understanding different kinds of ciphers (Site 1, Observer 1 &2), retaining curricular content (Site 1, Observer 1) and understanding vocabulary (Site 2, Observer 2).

Negative Emotional Engagement

Like cognitive engagement, there was more evidence of positive emotional engagement, but evidence of negative emotional engagement was observed and reported. Much of this negative emotional engagement occurred during discussions planned in the curriculum. One student was observed saying "this is boring" (Site 1, Observer 2) during a discussion early in the curriculum and during some discussions only a few hands were raised to participate (Site 2, Observer 2). Negative emotional engagement was also related to negative cognitive engagement. As students experienced frustration that they could not overcome, negative emotional engagement resulted.

One teacher reported in her weekly check-in that "Those that were struggling didn't want to continue. I paired a stronger student with the struggling student." Students also experienced negative emotional engagement when the pace of the curriculum was too slow (Site 1, Observer 1), when there was bad internet connection (Site 1, Observer 1) and on occasions when students entered the room with low energy to begin with (Site 1 & 2, Observer 1 & 2).

RQ3: In what ways does quantitative and qualitative evidence of engagement converge or diverge during a blended, transmedia curriculum?

More high engagement was reported and observed qualitatively than in quantitative profiles but the results converged and trended in same directions

A side-by-side comparison of quantitative and qualitative data (Creswell & Plano Clark, 2017) shows that while more students from the local sites clustered into high engagement profiles, the percentages of students clustered within each profile trended in the same direction with more students cognitively and emotionally engaged (Table 8). Because reports and observations are collected over the duration of the curriculum and across different sources, it is likely that the quantitative profiles may slightly underestimate levels of actual engagement.

Table 8
How student at local sites clustered compared to all

	Local students	All Students
High Cog	73.08%	63.24%
Low Cog	26.92%	36.76%
High Aff	73.08%	67.65%
Low Aff	26.92%	32.35%
High Global	80.77%	75.49%
Low Global	19.23%	24.51%

Quantitative and qualitative data converge to suggest third graders may not be cognitively engaged throughout the curriculum

Locally, exactly half of the students (13) clustered into the high profiles for cognitive and emotional engagement (Table 9). No local students clustered into both low cognitive and emotional engagement profiles.

Seven students each clustered in high cognitive and low emotional profiles and low cognitive and high emotional profiles. Four of the 7 students clustered as low cognitive and high emotional profiles were third graders. Two third graders clustered into the high profiles for cognitive and emotional. One third grader clustered into high cognitive and low emotional profiles. The qualitative and quantitative data converge here suggesting that this transmedia, blended curriculum is appropriate for some third graders but that certain content can be too challenging for others in this grade. Qualitative data did not reveal a difference in emotional engagement among grade levels which suggests third graders were at least as emotionally engaged as their older peers.

Table 9
Engagement profiles for students in the two local programs

Cognitive engagement	Emotional engagement	Count	Grade			
			3rd	4th	5th	6th
High	High	13	2	4	7	0
	Low	6	1	0	4	1
Low	High	7	4	1	2	0
	Low	0	0	0	0	0

Qualitative data suggest one indicator of quantitative engagement may not be representative

Qualitative data from teacher weekly check-ins and observations suggests that one of the digital activities whose mean error rate was selected as an indicator of cognitive engagement was unusually difficult for many students. This could have had an outsized influence on how students were clustered in the cognitive engagement profiles. Because mean error rates were not used for global engagement profiles, these profiles may be the most representative of engagement.

DISCUSSION

This mixed methods study used Halverson and Graham's (2019) framework for blended learning engagement to describe the facilitators of engagement built into a blended, transmedia curriculum, called CryptoComics, designed to teach young children about cryptology and cybersecurity.

Facilitators of engagement included: (1) anchoring the curriculum with a comic book, (2) blending digital and unplugged media, (3) supporting situational interest via a transmedia narrative and (4) designing for social-cultural relevance.

The study also sought to investigate learner engagement during curriculum implementation using a combination of person-centered and person-in-context measures of engagement (Sinatra et al., 2015) aligned to Halverson and Graham's framework (2019). The person-centered engagement measures (i.e., quantitative data) resulted in profiles of engagement suggesting the majority of the 204 students participating in the curriculum were highly engaged cognitively and emotionally while person-in-context data (i.e., qualitative data) from two local sites corroborated quantitative results and provided additional insights. For example, while the qualitative data corroborated that most students were engaged in the curriculum, these data also showed how the facilitators of engagement built into the curriculum influenced engagement. The qualitative results point to the transmedia narrative and social-cultural relevance as key facilitators of emotional engagement. Qualitative results show students personally connected to the characters, invested in helping the characters on their journey and were uninterested in exiting the curriculum even when class ended. Such data implies strong situational interest and students entering a state of ultimate engagement or flow (Csíkszentmihályi, 2021).

Qualitative data also show success with blending media in such a way that it leverages the strengths of digital and unplugged media and includes careful transitions across media. Evidence of both positive and negative cognitive engagement during times of media transition also suggests this is an area that could be strengthened in the curriculum. Strategies to investigate blended learning transitions quantitatively is an area for further inquiry.

Qualitative data also further clarify the quantitative profiles in that third graders may struggle with the curriculum content enough to hinder cognitive engagement. However, this study was not designed to consider grade differences. Additional research with a large group of diverse third graders is warranted to substantiate this assertion.

We sought to take care in identifying a blended learning engagement framework and found Halverson and Graham's (2019) work helpful in defining engagement and conceptualizing our measures. However, this study falls short in terms of advancing a "concrete definition and effective measurement of engagement" (Azevedo, 2015, p. 84). We believe this task becomes even more difficult when studying a transmedia, blended curriculum that extends over many weeks and across multiple media. In fact, our quantitative data suggests one indicator of cognitive engagement (i.e mean error rate for Number Ciphers) may have been a poor choice because students

struggled with that particular digital activity more than with others.

As we continue to implement the curriculum at other sites around the country, we are working to refine our quantitative indicators of engagement. Future study should also further explore the measurement of engagement, especially using data recorded by the technology tools. The qualitative indicators of engagement appeared to work well but observations were constrained by researcher location which makes mixed methods the most logical choice for robust exploration of engagement in this transmedia, blended curriculum.

While a mix of positive and negative engagement can be expected during implementation of a blended, transmedia curriculum, the majority of students were highly engaged cognitively and emotionally, and qualitative data revealed areas where negative engagement may be countered in the future. We are currently working to implement CryptoComics on a national scale and the cognitive and emotional engagement identified in this study bodes well for future implementations. It also bodes well for the future as knowledge of cryptology and cybersecurity is now essential to personal, national and global security.

DECLARATIONS

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