Education and Information Technologies
https://doi.org/10.1007/s10639-024-12617-y

Enacting algorithms: Evolution of the algorythmics storytelling

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Received: 13 October 2023 / Accepted: 28 February 2024

Abstract
Visual storytelling, particularly through dance choreographies as showcased in previous AlgoRythmics performances, has been effective in communicating relatively straightforward algorithms in an engaging and memorable way. Nevertheless, when addressing complex algorithmic concepts, an approach with greater expressiveness and flexibility becomes necessary. Consequently, this study introduces stage performances as an innovative solution, using cinematic representation to successfully convey and communicate these intricate concepts and processes. To evaluate the effectiveness of this approach, a short film was designed, produced, and showcased to a second-semester CS2 university course audience studying programming techniques. Following an opening scene that establishes the context, the subsequent three acts vividly depict ad hoc, greedy, and dynamic programming solutions in response to the posed programming challenge. After the screening, a questionnaire was administered, built on four key constructs of the Technology Acceptance Model, as well as other potential facilitating factors. The study reveals 100% positive perceptions of educational benefits, with the vast majority of students expressing agreement regarding the utility, enjoyment, engagement, creativity, filmic quality, and cognitive benefits of short films. Additionally, a remarkable 96% reported the intent to utilize this approach. Our subsequent Structural Equation Modeling analysis discovered that students whose learning styles were in sync with this approach demonstrated a robust correlation between their perception of the method's value, their enjoyment of the process, and their overall attitude towards this pedagogical method. This study confirms the potential of visual storytelling through short films as an effective tool for delivering programming education. The findings provide valuable insights for computer science educators seeking to engage learners and convey complex information in an attractive and effective way.

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Published online: 19 March 2024

Keywords Visual storytelling · Visualizing algorithms · Programming education

1 Introduction

Algorithms play a central role in Computer Science (CS) and half a century of experience shows that teaching-learning them effectively is a challenging educational issue (Katai, 2015). Since computer algorithms are abstract dynamic processes, more and more research suggests the use of dynamic visualizations to support learners in assimilating them (Shaffer et al., 2010). Although computer animations are most commonly used, the AlgoRythmics research group have proposed visualizations that illustrate the step-sequence of algorithms through dance choreographies (work viewable on the AlgoRythmics YouTube channel[1]). Previous research on the effectiveness of these educational instruments has highlighted two key strengths of this approach (Katai, 2015, 2020; Katai & Osztian, 2022, 2023); (i) the ability to captivate and generate interest through a compelling combination of art and science, and (ii) the activation of the so-called human movement effect (HME) (Paas & Sweller, 2012).

Visual storytelling is an integral aspect of folk dance, with motifs such as partner and group formations used to convey specific meanings and emotions. Partner formations in folk dances often symbolize unity, balance, and cooperation between two individuals, while group formations represent community, harmony, and solidarity among a larger group. The use of specific gestures and movements, such as handholding or arm interlocking, further emphasizes these themes and adds depth to the storytelling. In some folk dances, the use of props such as ribbons or handkerchiefs can also contribute to the visual storytelling by enhancing the movement and providing additional symbolism. Many of these elements have been incorporated into the AlgoRythmics folk dance representations.

The previous AlgoRythmics performances primarily focused on illustrating relatively simple algorithms, such as basic sorting and search strategies. These algorithms essentially boil down to a series of sequential steps involving comparisons or a combination of comparisons and swaps. Associating them with appropriate folk dance steps is a natural and intuitive analogy. However, in the field of computer science education, more complex algorithms, such as algorithm design strategies, hold significant importance. Notably, techniques like greedy and dynamic programming require a considerable amount of ingenuity to develop and are crucial for problem-solving in various domains. Dynamic programming, in particular, is widely recognized as a challenging programming technique (Enström, 2013; Giegerich, 2000). As a result, the idea emerged to extend the AlgoRythmics approach to incorporate these complex algorithms as well. Considering the relatively tighter style characteristic of classical dances, we recognized a better opportunity to portray these sophisticated algorithms through stage performances. Our decision was further supported by the preservation of the above mentioned two key strengths of AlgoRythmics videos.

Cinematic storytelling provides a captivating and effective framework for presenting complex concepts, including algorithmic content, in a manner that is engaging and

[1] https://www.youtube.com/user/algorythmics

impactful. The use of narrative has long been theorized to enhance engagement, motivation, and learning within educational settings. Extensive research, as highlighted by Ferguson et al. (2020), consistently supports the positive effects of a strong story structure on learning outcomes. In a recent quantitative meta-review focused on the impact of narrative elements in games, Wouters and Van Oostendorp (2017) reported compelling evidence for the influential role of narratives, particularly in terms of motivation. Similarly, Jemmali et al. (2019) found that in the context of CS educational game design, participants who engaged with a rich narrative version of the game exhibited heightened levels of engagement.

Moreover, previous studies have demonstrated that the choreography representations used in AlgoRythmics dancing may incorporate elements that can be distracting, such as specific dance steps, catchy music, and striking attire. These distractions have the potential to impede the learning process (Katai & Osztian, 2022). However, by presenting algorithmic processes through stage performances that emulate cinematic experiences, these distractions can be minimized while still maintaining the core principles of HME. For instance, the attire and movements of the performers can seamlessly be aligned with the narrative. The music serves as an inspiring backdrop, in contrast to the dance choreography where the music took a foreground position, guiding the dancers' movements. In addition, this approach introduces further advantages, such as the inclusion of an intriguing story-line, dialogue, and a familiar format that is particularly appealing to young learners. It is worth noting that short-video formats have gained immense popularity among young people, with platforms like TikTok and Instagram Reels boasting millions of active users on a daily basis. Leveraging this trend, an educational approach that combines concise and visually stimulating designs holds great potential to deliver CS content in a way that piques the students' curiosity and sustains their attention.

In response to the aforementioned limitations in previous AlgoRythmics visualizations, this study addresses the corresponding research gap by introducing a novel approach. Utilizing cinematic storytelling not only preserves the strengths of current AlgoRythmics representations but also showcases the potential to visually represent more complex algorithms while circumventing distracting elements associated with the dance choreography representations. This advancement paves the way for heightened clarity and effectiveness in AlgoRythmics algorithmic visualizations.

Given that the primary goal of this research is to delve into the educational potential inherent in the cinematic representation of algorithms, specifically focusing on students' perceived effectiveness, satisfaction, and their inclination to adopt these instructional tools, an expanded variant of the Technology Acceptance Model (TAM) (Davis, 1989) serves as the theoretical foundation for this study. According to the TAM attitude is the key component of the adoption behavior, which in turn depends on two beliefs: perceived usefulness (PU) and perceived ease of use (PEOU) (Davis, 1989). In addition, Dogruel et al. (2015) proposed enjoyment as a crucial factor that influences the acceptance and use of the system. Regarding the PEOU component, Altin Gumussoy et al. (2018) found compatibility (adopted from the Innovation Diffusion Theory) to be the most influential factor. Since our purpose was to evaluate the effectiveness of an educational short film presented by a teacher in front of a class, we included the following three factors in our model: perceived usefulness, perceived enjoyment, and compatibility. We also examined potential facilitating factors specific to the investigated learning context and technology.

2 Background

The AlgoRythmics project, which has been running for two decades, has entered its third phase. The initial phase, titled 'Multisensory Computer Science Education,' focused on enhancing the teaching and learning process of elementary computer algorithms. The research group introduced a method in which the 'loop structure of the algorithms' was represented by strings of musical notes. Additionally, the software tool developed enabled students to tap out the 'rhythm of the loop structure' using the keyboard, enhancing their perception of the 'pulsation and rhythm of the algorithms' (Kátai et al., 2008).

The 'algorithm dances' were developed within the framework of the second phase (Katai & Toth, 2010). The authors created dance choreography representations for ten fundamental computer algorithms. Seven sorting strategies were illustrated through folk dance performances, while three search algorithms were represented using Flamenco and ballet choreographies. By choosing folk dances, our intention was to imbue choreographies with a touch of intercultural education, as these dances inherently mirror the cultural diversity prevalent in our region. Consequently, the AlgoRythmics collection embraces the fusion of science and art, transcending ethnic boundaries (Katai, 2014a). The accompanying research explored the potential of this art-science fusion and how representing algorithms through human movement can enhance the effectiveness of algorithm visualizations (Katai, 2015, 2020; Katai & Osztian, 2022, 2023).

A third phase has begun, transitioning the project from the dance floor to the stage. The current initiative to illustrate complex CS algorithms through captivating short films intersects with at least three research areas: learning algorithms from human movement effect enhanced dynamic visualizations, boosting motivation by combining art and science, and sustaining student engagement through cinematic depictions. In this section, we summarize previous results in these fields and highlight their implications for the AlgoRythmics approach.

2.1 Learning algorithms from human movement effect enhanced dynamic visualizations

The ability to understand how computer algorithms work depends on an individual's capacity to construct a clear mental image of the machine's state at each computational step (Turing, 1950). Visual aids have the potential to support this internal building process, allowing students to better understand algorithms (Katai, 2014b). Accordingly, dynamic visualizations have been widely used by many computer science teachers in recent decades to demonstrate the dynamic behavior of algorithms (Shaffer et al., 2010).

However, it is widely acknowledged that learning from external representations can be cognitively demanding (Leahy & Sweller, 2011). Although animations are known to motivate learners, research on their impact on understanding dynamic concepts has produced inconsistent results (Ainsworth & VanLabeke, 2004). The most commonly cited explanation for this variability in effectiveness is the transient nature of animations (Leahy & Sweller, 2011; Stenning & Monaghan, 2000). When viewing an animation, the viewer must simultaneously select and process current information while recalling and integrating previous information, resulting in a high level of cognitive demand on working memory.

In the field of dynamic visualizations, recent research has revealed a surprising result: the 'transient information impediment' mentioned above seems to disappear when learning is focused on human movement (Wong et al., 2012). Consequently, an important feature of AlgoRythmics videos is that the steps of the algorithms are represented by human movements (Katai & Osztian, 2022). Although most studies on HME focused on learning tasks that directly involve human movement (Boucheix & Forestier, 2017; Rekik et al., 2019), de Koning and Tabbers (2011) emphasize its significance in learning with animations for non-motor tasks as well. They argue that all types of visualization, including those related to concepts, can be improved by connecting the content to the learner's own body or actions. Bergner et al. (2020) found support for the idea that offline embodied cognition can significantly aid in the acquisition of new abstract knowledge, particularly in the fields of mathematics and data science. Lan et al. (2018) observed that students exhibited superior learning outcomes in English foreign language listening performance when observing their own 3D avatars performing motions, as opposed to physically executing the motions themselves or doing nothing.

Algorithmic concepts can be easily connected to human movements. Many definitions of algorithms use terms such as 'step sequence' and 'proceeding through', which imply a connection to physical actions. In the algorithmic context that forms the basis of the present research, the objective is to navigate optimally from the top of a pyramid to its base through a series of decisions, advancing from level to level. To activate the HME, performers employ lively facial expressions, dynamic body language, and expressive movements to externalize the decision situations they encounter. This encompasses illustrating the choice-making process and depicting the progression of the solution-seeking journey. We ensured that their movements maintained a one-to-one relationship with the steps of the algorithms being presented.

2.2 Boosting motivation with a salient blend of art and science

Motivation is a crucial factor for learning to occur. One effective strategy for enhancing it is by piquing students' curiosity (Day et al., 1971; Kashdan et al., 2004). Techniques such as introducing novelty, incongruity, and surprise can effectively arouse curiosity and counteract apathy (Berlyne, 1960; Keller, 1983). Katai (2015, 2020) argues that the AlgoRythmics dance-choreographies are effective in sparking curiosity due to their prominent science-art pairing. Numerous feedback comments on the published videos confirmed this quality of the AlgoRythmics approach: "This is the greatest piece of art I have ever seen!"; "I think I just found a new continent"; "Beautiful piece of art to explain computer science, this is so EPIC!"; "Art + Science = Intelligent entertainment."; "This is science that's joy! I posed the exercise to my students to extract the partitioning algorithm out of the quicksort dance."; "I have been using these videos with my high school CS classes for at least 5 years. It is one of my favorite series of lessons and the kids love them. Thank you for creating these amazing videos."

By transferring the project to the stage, a prime location for artistic expression, our aim is to uphold the benefits derived from the fusion of science and art in AlgoRyhtmics productions. Furthermore, stage performances that offer cinematic enactments of algorithmic processes can serve as an exceptionally captivating educational format for young learners.

2.3 Sustaining student engagement through cinematic depictions

Visual storytelling is a powerful tool that improves the comprehension and recall of complex information (Williams, 2019). Although it takes many forms and serves various purposes, movies are uniquely capable of telling stories through motion, making them particularly adept at stimulating brain activity and displaying events in coherent narrative structures (Kroeber, 2006). Lindsay (1970) suggested that movies should be considered as 'moving sculptures'. Achieving this effect requires filmmakers to carefully combine various elements, including story plot, cinematography, camera style, lighting, set design, editing, sound design, spacing, and even color, to engage the audience both cognitively and emotionally (Bellantoni, 2012; Murch, 2001). Edgar-Hunt et al. (2010) link these elements to the notion of film language. According to Bordwell and Thompson (2012), immersive films are characterized by creativity and expressiveness. These characteristics are especially important for creating effective mise-en-scène, particularly in the case of staged choreographies (Kroeber, 2006).

McKee (1997) highlights the importance of creating stories that resonate with audiences. Jenkins (2006) suggests that contemporary media consumers, particularly the youth, are highly motivated to seek out specific types of media experiences. This is supported by Veenstra et al. (2020) finding that young people are willing to engage in extensive search efforts to find the desired media experiences. All these suggest that incorporating complex algorithmic concepts within popular cinematic contexts may be an effective method for captivating the interest of young learners and promoting CS courses that are both intellectually stimulating and engaging.

3 Unraveling the factors shaping user attitude within the framework of the technology acceptance model

Attitude refers to a psychological construct that encompasses an individual's evaluation, feelings, beliefs, and predisposition towards a person, object, idea, or situation. It represents a person's overall stance or disposition, which can influence their thoughts, behaviors, and responses in relation to the target of their attitude. Attitudes are typically formed through a combination of cognitive, affective, and behavioral components.

The cognitive component involves beliefs and thoughts about the target, the affective component relates to the emotional response or evaluation associated with the target, and the behavioral component encompasses the behavioral tendencies or inclinations towards the target. Several influential studies have contributed to elucidating the significance of the attitude factor and its measurement.

Davis (1989) introduced the Technology Acceptance Model (TAM), emphasizing perceived usefulness (PU) and perceived ease of use (PEOU) as determinants of user attitudes towards technology. According to this model, users develop an initial intention to adopt a technology, which subsequently motivates them to become active users of the system (Altin Gumussoy et al., 2018). Based on the theory of planned behavior (TPB) (Ajzen, 1985, 1991), the following dependency chain can be established: behavior is determined by factors such as behavioral intention, which is shaped by the individual's attitude. Given that our research measured the attitude factor after a demonstrative learning session and did not involve actual subsequent use, we treated the intention to use as an indicator of the behavioral component within the attitude construct.

Despite its central role within TAM, attitude was removed from some expanded versions of this framework and replaced with other factors (e.g. TAM2 proposed by Venkatesh and Davis (2020); UTAUT: unified theory of acceptance and use of technology by Venkatesh et al. (2003)). However, several subsequent research studies have provided support for the role of attitude toward use in the TAM (Kasilingam, 2020; Lau & Woods, 2008; Teo, 2010). As a result, the TAM has remained a core model in many research studies and continues to demonstrate its influence and popularity, surpassing models such as the UTAUT (Kim et al., 2010).

While PU and PEOU are widely recognized as essential elements in the TAM, there are studies suggesting the inclusion of additional factors to further enhance the explanatory capability of this framework (Altin Gumussoy et al., 2018). For instance, Dogruel et al. (2015) pointed out that most existing TAM research has focused mainly on task-related aspects of the use of new media technology, while neglecting the role of entertainment aspects. This trend can be traced back to the original TAM framework proposed by Davis (1989), which was designed to examine technology adoption and use behaviors in the workplace context. Only a few studies have explored the role of intrinsic motivating factors, such as enjoyment or playfulness, in influencing system use (Davis et al., 1992). Dogruel et al. (2015) concentrated on media entertainment technologies and recommended replacing PU with the enjoyment factor. Since our objective was to evaluate the efficacy of engaging educational short films within the context of CS education, we included both the perceived usefulness and the perceived enjoyment (PE) factor in our analysis.

TAM was also extended along another dimension, as suggested by the Innovation Diffusion Theory (IDT) (Agag et al., 2019; Giovanis et al., 2012). IDT proposed a set of five innovation attributes to explain user adoption rates (Rogers Everett, 1995), but subsequent research confirmed only three of them: relative advantage, compatibility, and complexity (Tornatzky & Klein, 1982). Since the construct of relative advantage is similar to PU, and complexity is similar to PEOU (Moore & Benbasat, 1991), compatibility is the only significant innovation characteristic not directly addressed by TAM (Giovanis et al., 2012). However, since compatibility was found to be the most influential factor for PEOU (Altin Gumussoy et al., 2018), we replaced PEOU with this factor in our investigation. This decision was also justified by the fact that in the educational context we propose, media use is limited to students viewing short films presented by the teacher.

Davis (1989) acknowledged that while TAM is valuable for explaining the behavioral intention of technology usage, it is essential to consider additional variables related to the specific technology to gain a comprehensive understanding of its acceptance. In line with this, the questionnaire we developed also aimed to target potential facilitating factors specific to the educational setting under examination. These factors were categorized into three groups: cognitive benefits, engagement factors and benefits, and filmic attributes.

4 Pyramid game: An engaging algorithmic movie

To achieve an elevated artistic quality of the AlgoRythmics dance choreographies, we partnered with skillful and experienced dance troupes. Close coordination between CS education researchers and choreographers was necessary to create harmonious art-science blends. A similar collaboration is behind the new video. We teamed with a teacher choreographer from a University of Arts and a proficient cinematographer. Students from the University of Arts translated the designed algorithmic scenarios into stage performances and alongside them CS students paid attention to the clarity of algorithmic content.

The outcome, the produced short movie is available on the AlgoRythmics YouTube channel [2].

4.1 Focusing on educational goals through targeted programming strategies

The pre-production phase was dedicated to crafting an artistically enhanced floor with a focus on educational goals, as outlined by Katai and Toth (2010). Our primary objective was to create a visually captivating platform that not only showcases CS algorithms but also actively engages users with complex algorithmic concepts. The ultimate aim was to facilitate students' exposure to various algorithmic paradigms, with a specific emphasis on illustrating greedy and dynamic programming techniques.

Mastery of both greedy and dynamic programming strategies holds a pivotal role in computer science education, equipping students with essential skills to navigate algorithmic challenges. The perpetual challenge within educational contexts revolves around effectively visualizing these often abstract concepts. Through our innovative expression and the immersive Pyramid game implementation (Fig. 1), we adeptly highlighted the fundamental characteristics of the two methods.

In the Pyramid game we designed, actors are positioned on 15 chairs arranged in a pyramid structure with five levels. Once seated, participants are unable to rise until they

[2] https://youtu.be/4Ogkw6OP9-Q

Fig. 1 Enacting of the greedy and the dynamic versions of the algorithm

successfully tackle an algorithmic challenge. Each performer is assigned a number, and their goal is to amass the maximum sum achievable by selecting one number per level, advancing from the top of the pyramid to its base — level by level, and moving from neighbor to neighbor. The algorithms to be illustrated are presented in such a way that the actors strive to find solutions to the task by applying the corresponding strategies.

This visual approach not only demystifies these main strategies but also cultivates a tangible and engaging learning experience, facilitating students in comprehending the intricacies of algorithmic problem-solving with clarity and accessibility.

4.2 Focusing on creative goals using particular dramatic effects

During the film-making process, we managed to strike a balance between artistic expression and scientific accuracy, further enhancing user engagement. In order to focus on cinematic effects as well, the visualization technique was discussed in detail with a skilled cinematographer, and we decided to use an overhead filming technique with various camera angles and illustrative figures to establish a stronger connection between the protagonists and the viewers, fostering a social-belonging effect and promoting user engagement.

Furthermore, the artistic choices focused on creating a specific atmosphere and mood by selecting appropriate colors and film elements, inspired by the visual style of popular escape room-themed movies. The pyramid scene was designed using a combination of dark red chairs and a black floor to create a sense of tension and anticipation. The use of props and costumes, such as individual numerical values on paper and a red light, were also incorporated to enhance the immersive experience and heighten the dramatic tension.

The intensity of the algorithmic film increased steadily, and the mood was effectively conveyed through the use of flickering red lights on the players' necks and the heightened tone of the narration. The climax of the film was reached when the players realized that they had one final opportunity to solve the problem. To create an even more impactful scene, a unique special effect was incorporated in which the actors could read each other's minds, adding an extra layer of suspense and intrigue to the story.

4.3 Story-line layer

To create a captivating cinematic atmosphere that fully engages viewers with the core concept of the Pyramid game, the algorithmic film was recorded in a theater. The narrative unfolds in three distinct segments: an intriguing introduction setting the context, a main section portraying the three programming approaches (ad-hoc, greedy, and dynamic programming), interwoven with insightful explorations of psychological facets, and a compelling outro anticipating the sequel (*"You may have won the battle but you are far from winning the war"*).

We introduced the ad hoc approach as a reference point. An ad-hoc approach usually involves improvisation, often in response to an unpredictable situation; hence, it can be considered a strategy-less approach. The greedy technique relies on locally optimal choices, prioritizing immediate gains, but it may not guarantee the optimal solution. In contrast, dynamic programming ensures optimal solution by constructing it from the optimal solutions of the sub-problems.

The ad hoc method is integrated into the story-line in such a way that, at each step, the current female performer must choose between a boy and a girl, consistently opting based on gender (from girl to girl). In the greedy scene, the current performer decides solely based on the numbers held by its neighbors, selecting the one with the larger number. As a result, only actors along the presumed optimal route secure a role in the solution-building process. Since all decisions are rooted in locally available information, this method reflects an egocentric attitude, prioritizing individualism over collaboration. As an additional psychological aspect, this approach also illustrates the human tendency to choose the easiest solution to a problem, regardless of its negative consequences.

Contrastingly, within the framework of dynamic programming, all sub-problems are systematically solved, ensuring that all performers secure a role during the solution-building process. Consequently, this approach authentically illustrates the inherent value of teamwork. It also underscores the significance of cooperation in achieving goals, not only in games but also in real-life situations, reinforcing the message that unity often paves the path to success.

4.4 Post-production layer

Throughout the post-production phase, the primary focus was placed on amplifying the video's expressiveness and viewer engagement. To achieve this, a range of creative strategies were implemented. A professional cinematographer thoughtfully chose specific camera angles, alternating between them to uphold the film's suspense and intrigue, while also providing a clear perspective on the actors' facial expressions and gestures. Alongside careful camera work, several instructional figures were incorporated to further elucidate the techniques being showcased, including overviews of the solutions as illustrated in Fig. 2. These deliberate choices throughout the post-production process ensured that the film's educational message was as compelling and clear as possible.

Fig. 2 Showcase of different captivating cinematic elements, enactments and visualizations

The color palette chosen for the film comprised mainly of red, black, green, and white hues, each selected for their symbolic connotations. Red was utilized to denote incorrect answers, and to convey a sense of tension, thrill, and captivity. In contrast, green was employed to indicate correct answers and helpful instructions, while also symbolizing freedom. The color white marked the extraordinary, such as mind-reading occurrences. Black served as the dominant background color, amplifying the atmosphere of suspense and anticipation for viewers.

5 Study

This section presents the methodology employed in this study, aimed at evaluating the perceived effectiveness and impact of a supplementary short film in a university programming techniques course. Our primary focus was to assess if the film, used as a single-session intervention, could potentially enhance students' learning of certain advanced programming techniques. Participants in the study were undergraduate students who already had a foundational understanding of these techniques. The subsequent subsections offer a detailed account of the participants, the intervention, the associated tasks, and the approach to data analysis.

5.1 Participants

The study involved a cohort of 54 undergraduate students, aged 18 to 20, who were enrolled in either Computer Science or Informatics degree programs. At the onset of university enrollment, students typically demonstrate varying levels of prior programming knowledge, a diversity that shaped the composition of the subjects in this study: 25% with no prior experience, 18% with 1-3 years, and 47% with 4 years of high school programming experience. However, a baseline in basic programming competence was achieved, as all participants attended a first-semester CS1 course.

Additionally, a few participants were exposed to AlgoRythmics videos during their high school studies, and all of them encountered these videos during a parallel seminar with the CS1 course, providing them with familiarity with the pedagogical approach of integrating art and science.

Out of the initial 54 students, 51 successfully completed the questionnaire designed to assess student feedback regarding the analyzed film's characteristics and potential benefits. This subset of participants forms the core dataset for this study.

5.2 Apparatus and stimulus information

The key stimulus used in the intervention was the concise 7-minute film detailed in Section 4. This film provided supplemental educational content, elaborating on two key programming techniques and their properties.

The intervention took place in an amphitheater, a familiar environment for the students where most of the course was conducted. Consistent with the typical course delivery, a laptop connected to a video projection system was used. The significant shift in this phase was in the content displayed; instead of the usual PowerPoint slides, the short film was projected onto a large screen measuring approximately 12 square meters.

The seating arrangement and viewing conditions were maintained as usual. The first row was 5 m away from the projected image, and the last row was situated at a distance of 14 m. The content occupied the whole projection screen, and the viewing angle ranged from -8 degrees at the middle of the 12th row to +22 degrees at the middle of the first row, ensuring all students could effectively access the visual stimuli.

5.3 Procedure and measurements

The study was initiated with a preparatory phase, held a week prior to the main intervention. In this initial phase, students were introduced to two specific programming techniques. This strategic groundwork provided them with the fundamental understanding necessary to engage with the content of the forthcoming short film.

The main intervention involved the screening of the short film, a presentation designed to elucidate the previously introduced programming techniques. Following the film screening, students were required to complete, anonymously, a comprehensive questionnaire. This instrument was designed to not only to probe their perceptions of the film's various aspects and potential benefits, but also to gauge key constructs from

Table 1 Statements evaluating various characteristics and aspects of the short film

Dimension	Item names	Items
Engagement	EF.Entertainment	The short film provided a high entertainment value.
Factors	EF.ProductionValue	The short film had a high production value.
	EF.Premise	The premise (escape room) was intriguing.
	EF.Expressive	The short film was expressive.
	EF.Immersive	The short film was immersive.
	EF.Creative	The short film was creative.
	EF.Pacing	The pacing of the story was appropriate.
Filmic	FA.Story-plot	I appreciate as important the presence of the story-plot.
Attributes	FA.LiveAction	I appreciate as important the use of live-action performances.
	FA.CameraWork	I appreciate as important the cut and switch of camera angles.
	FA.Atmosphere	I appreciate as important the mood and atmosphere.
	FA.Choreography	I appreciate as important the choreography.
	FA.Cinematography	I appreciate as important the depicted cinematography.
	FA.NonVerbal	I appreciate as important the facial expressions, body language of the actors.
	FA.SoundDesign	I appreciate as important the sound design, narration and sound effects present.

the Technology Acceptance Model (TAM). These constructs, which include Perceived Utility, Perceived Enjoyment, Compatibility, and Attitude, were measured to evaluate students' receptivity towards the pedagogical approach employed in the film.

The specifics of the questionnaire are articulated in three tables: Table 1 displays the factors and corresponding questions used to assess various characteristics of the short film, Table 2 delineates the items intended to evaluate the potential benefits experienced by the audience, and Table 3 presents the items measuring the key TAM constructs.

To capture a range of responses, participants were asked to rate each statement on a Likert scale from -3 (strongly disagree) to 3 (strongly agree), with 0 indicating a neutral position.

Table 2 Statements evaluating the potential benefits experienced by the audience

Dimension	Item names	Items
Cognitive	CB.Educational.	The short film provided a high educational value.
Benefits	CB.Understanding	The learning experience deepened my understanding of the subject.
	CB.Clarity	The algorithmic strategies were clearly depicted.
Engagement	EB.Attention	The movie engaged my attention.
Benefits	EB.Curiosity	The movie engaged my curiosity.

Table 3 Statements used to assess the TAM constructs

Dimension	Item names	Items
Perceived	PU.Quicker	Using such short films during a class would enable me to learn and deepen algorithmic concepts more quickly.
Utility	PU.Performance	Using such short films during a class would improve my learning performance and grades.
	PU.Efficiency	Using such short films could help me get the most out of my time while learning.
	PU.Knowledge	Using such short films may improve my knowledge.
	PU.Easier	Using such short films would make it easier to accomplish my learning tasks.
	PU.Overall	Using such short films would be overall beneficial.
Perceived	PE.Enjoyable	The learning experience was enjoyable.
Enjoyment	PE.Exciting	The learning experience was exciting.
	PE.Pleasant	The learning experience was pleasant.
	PE.Interesting	The learning experience was interesting.
	PE.Immersive	The learning experience was immersive.
Compatibility	C.Changes	The use of such short films may imply major changes in how I learn.
	C.Incorporation	It would be easy to incorporate such short films in my learning process.
Attitude	A.Worthwhile	Using similar educational short films to learn algorithmic concepts is a good idea.
	A.Positivity	I am positive towards using visual media to better understand algorithmic concepts.
	A.Appreciate	I would appreciate the availabilty of similar short films as learning instuments.
	A.WouldUse	If available, I would use such short films in my learning process.

In addition to these items, we also evaluated the students' prior usage habits of AlgoRythmics content beyond the classroom and their perceived value of the short film approach in comparison to traditional videos or animations. This evaluation was based on two specific items:

- $Eval.Use$: "I often use/used existing AlgoRythmics videos in my learning process."
- $Eval.Comp$: "Overall, the short film approach (story-line, live-acting etc.) provides a richer and more valuable learning experience than the viewing of simple videos or animations."

5.4 Statistical analyses

Descriptive statistics were initially used to examine and visualize student feedback on context-specific and technology-related facilitating factors, along with the TAM constructs, based on the responses to the questionnaire.

Subsequently, Structural Equation Modeling was utilized to determine the influence of various latent factors on Attitude, allowing a more profound insight into the complex interplay among the variables.

6 Results

Figures 3 and 4 presents the distribution of the seven-point Likert scale responses in a clear and intuitive way using Likert plots, also known as a diverging stacked bar charts. The width of each horizontal bar represents the percentage of respondents who gave a particular response. For each item, the three percentages of the left, middle and right summarize the distribution of the disagreement, neutral and agreement responses. Furthermore, the bars are color-coded to indicate the degree of agreement or disagreement, with darker shades representing stronger responses.

Table 4 presents key statistical analyses of the questionnaire responses, offering insights into participants' perceptions. The mean shows the average rating for each statement, indicating overall consensus. Standard deviation reveals response variability; lower values suggest consistency while higher values indicate broader response ranges. The p-values from one-sample t-tests examine if mean ratings significantly differ from the neutral midpoint. Finally, Cohen's d effect sizes represent the magnitude of difference between the mean and neutral point.

The high mean scores, exceptionally low p-values, and very high Cohen's d values across all factors strongly suggest that the students perceived the medium and its content as highly beneficial, aligning with their educational expectations. Altough direct learning outcomes were not measured, these indicators reflect a strong positive reception and perceived effectiveness among the audience.

Certainly, it is also crucial to consider potential biases that could have impacted the self-reported results. While the questionnaire's anonymity may have mitigated social desirability bias, other influences like the novelty, halo effect, acquiescence, confirmation bias, remain pertinent factors. These biases might have shaped the students' responses, especially given the distinctive nature of the educational medium.

6.1 Student feedback on contextual and technology-specific facilitating factors

The most obvious pattern in Fig. 3 is the overall dominance of the responses voicing some level of agreement with the items in the questionnaire. The percentages range from 100% for the perceived educational benefit $CB.Educational$ to 67% in the case of the feedback on the immersion engagement factor $EF.Immersion$. Neutral opinions range from 0% to a maximum of 31%, again for $EF.Immersion$. Disagreement

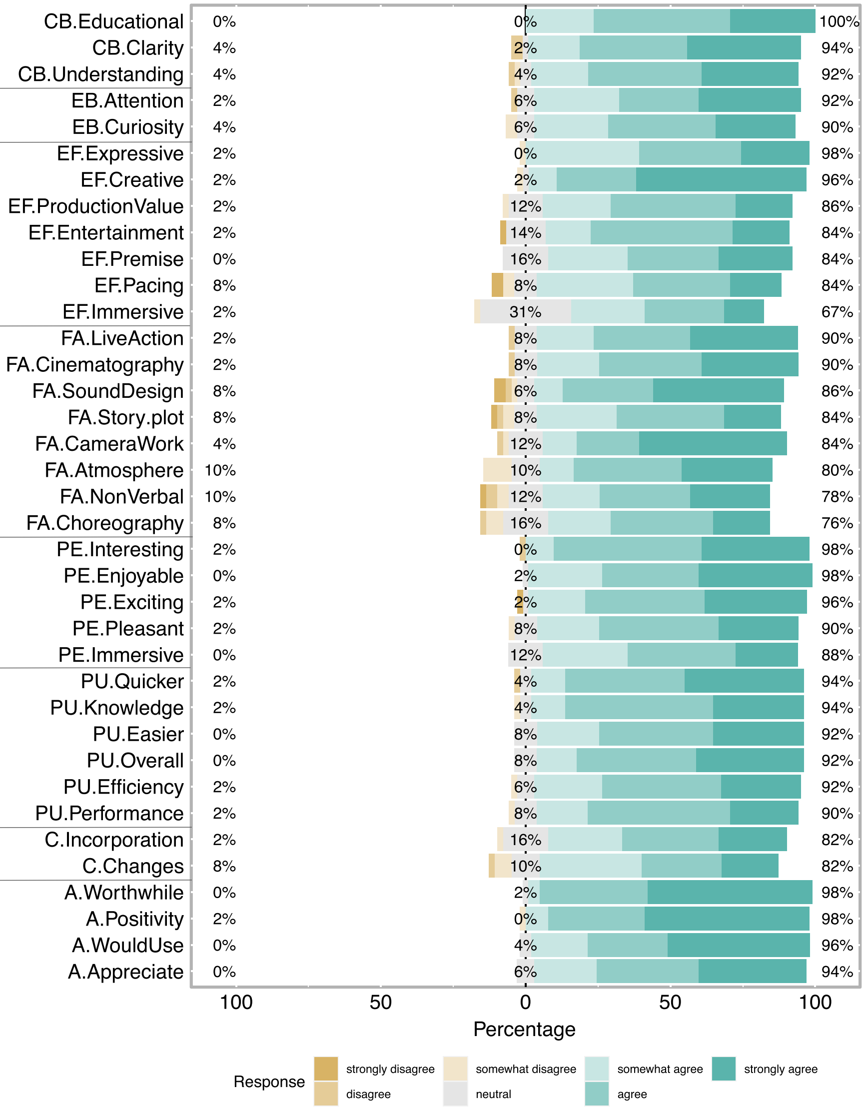

Fig. 3 Distribution of the seven-point Likert scale response alternatives for the various queried dimensions, expressed in percentages

percentages are low across all dimensions, reaching 8%-10% mostly when evaluating the importance of certain characteristics of the short film.

The median score values of the analyzed factors also support the overall positive outlook. In the case of 34 out of 37 (91.84%) items at least 50% of the students "agreed" or "strongly agreed" that such short films are useful, enjoyable, engaging, filmic and bring cognitive and attentional benefits.

Regarding the dimensions of Filmic Attributes and Engagement Factors, it can be observed that certain characteristics (such as immersion, pacing, soundscape, story-

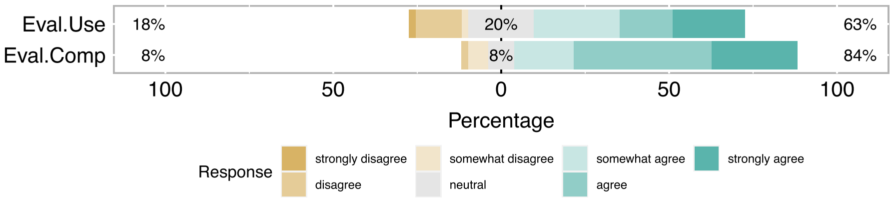

Fig. 4 Distribution of the seven-point Likert scale response alternatives for the evaluation of past usage and overall comparative advantage, expressed in percentages

plot, and atmosphere) were perceived by a minority of the audience as relatively unimportant, while others, such as expressiveness, creativity, live-action, and cinematography, were almost universally recognized as significant and important. An extremely encouraging aspects of the results is that over 50% of the students responded with a "strongly agree" rating when evaluating the creativity of the presented cinematic depiction.

6.2 Student feedback on the TAM constructs

For the dimension Perceived Enjoyment and Perceived Utility, the mean of the item scores are $M_{PE} = 1.9686\ (SD_{PE} = 0.2041)$ and $M_{PU} = 1.9869\ (SD_{PU} = 0.1219)$. These average agreement loads are very close to 2, the value of the "agree" point. The PU arises from arousal of interest and intellectual engagement and the questionnaire captured these aspects along the Cognitive and Engagement Benefits dimensions. Both of these have a high agreement load, with $M_{CB} = 2\ (SD_{CB} = 0.0707)$ and $M_{EB} = 2.0882\ (SD_{EB} = 0.0555)$. Based on these result and looking also at the distribution of the answers, it is clear that the audience enjoyed and positively appreciated the short film based learning experience.

In the case of the Compatibility dimension, the feedback reveals that 16%-18% of the students have some degree of concern or perceived difficulty on how they could integrate short films in their CS study. Also, the percentages of "strongly agree" answers is the overall lowest for this dimension. This result underline that the compatibility factor deserves special attention.

With a mean of scores value of $M_A = 2.2941\ (SD_A = 0.2068)$ the Attitude is by far the dimension with the highest agreement load. With the exception of $EF.Creative$, it exceeds even the score of singular items. Furthermore, both $A.WorthWhile$ and $A.Positivity$ attitude had the maximum median value indicating that at least 50% of the students "strongly agreed" that using similar short films to learn and understand algorithmic concepts is a good and fruitful approach. These excellent ratings could be explained by the influence of some very significant factors that are not accounted for in the model, or more probably, emergence arising from the collective interaction between components.

Figure 4 presents the distribution of responses evaluating the past usage of AlgoRythmics educational videos $Eval.Use$ ($M = 0.8627$, $SD = 1.6972$) and the overall comparative assessment of the short film format $Eval.Comp$ ($M = 1.6666$, $SD = 1.2274$). 63% percent of students utilized AlgoRythmics videos in their learn-

Table 4 Statistical Analysis of Student Feedback

	Mean	SD	p-value	Cohen's d
CB.Educational	2.0588	0.7324	< .0001	2.8109
CB.Clarity	2.0196	1.14	< .0001	1.7716
CB.Understanding	1.9216	1.0926	< .0001	1.7587
EB.Attention	1.8627	1.0958	< .0001	1.6999
EF.Expressive	1.7843	0.8789	< .0001	2.0301
EF.Creative	2.3922	0.8962	< .0001	2.6693
EF.ProductionValue	1.6667	0.9933	< .0001	1.6779
EB.Curiosity	1.7843	1.0453	< .0001	1.7071
EF.Entertainment	1.6667	1.1431	< .0001	1.458
EF.Premise	1.6667	1.0328	< .0001	1.6137
EF.Immersive	1.1961	1.0958	< .0001	1.0915
EF.Pacing	1.3725	1.3411	< .0001	1.0235
FA.LiveAction	1.9412	1.1029	< .0001	1.76
FA.SoundDesign	1.902	1.5133	< .0001	1.2568
FA.Cinematography	1.8824	1.089	< .0001	1.7285
FA.Story-plot	1.4706	1.3016	< .0001	1.1298
FA.CameraWork	2.0196	1.2726	< .0001	1.5869
FA.Atmosphere	1.7059	1.2852	< .0001	1.3273
FA.Choreography	1.4118	1.2518	< .0001	1.1278
FA.NonVerbal	1.4706	1.4745	< .0001	0.9974
PE.Interesting	2.1961	0.8722	< .0001	2.5178
PE.Enjoyable	2.098	0.8545	< .0001	2.4552
PE.Exciting	2.0196	1.0675	< .0001	1.8919
PE.Pleasant	1.8431	0.9874	< .0001	1.8667
PE.Immersive	1.6863	0.9485	< .0001	1.7779
PU.Quicker	2.1373	1.0004	< .0001	2.1364
PU.Knowledge	2.0588	0.8812	< .0001	2.3365
PU.Easier	1.9412	0.9255	< .0001	2.0975
PU.Overall	2.0784	0.9131	< .0001	2.2763
PU.Efficiency	1.8627	0.9596	< .0001	1.9412
PU.Performance	1.8431	0.946	< .0001	1.9484
C.Incorporation	1.6078	1.0785	< .0001	1.4908
C.Changes	1.3922	1.2013	< .0001	1.1589
A.Worthwhile	2.4902	0.6745	< .0001	3.6921
A.Positivity	2.4314	0.8063	< .0001	3.0153
A.WouldUse	2.2157	0.9014	< .0001	2.458
A.Appreciate	2.0392	0.9157	< .0001	2.227

ing journey. 84% of the respondents rate the short film format as providing a superior and more valuable learning experience overall. This corroborates with the very high 96% reported for the intent to use ($A.WouldUse$).

6.3 Interrelationships among movie evaluation items

The heatmap in Fig. 5 illustrates the pairwise Pearson correlation coefficients between the various movie evaluation metrics. The majority of correlations appear positive, reflective of the generally positive skew in ratings presented in Fig. 3. Strong positive correlations are primarily clustered along the main diagonal, reflecting the internal consistency of dimensions like Perceived Enjoyment and Perceived Utility.

In the heatmap, we also observe a moderate intercorrelations among distinct dimensions, particularly between Perceived Enjoyment, Engagement Factors, and Filmic Attributes. This pattern suggests that Perceived Enjoyment is not just an isolated affective response, but is intricately linked with how engaging and aesthetically appealing the students find the movie.

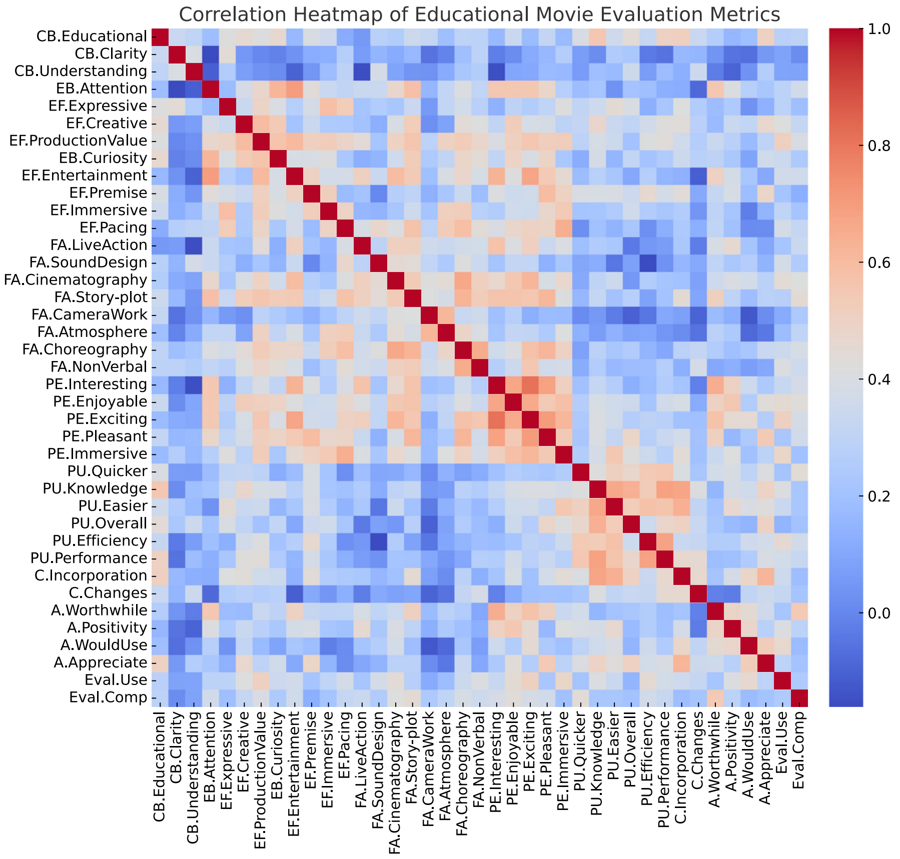

Fig. 5 Heatmap of correlation coefficients among movie evaluation metrics

6.4 Impact of prior algorythmics exposure on movie evaluations

To examine the influence of prior AlgoRythmics exposure on students' assessments of the educational movie, we analyzed the correlation coefficients of the variable $Eval.Use$ with other evaluative metrics. These coefficients, displayed in Fig. 6, were sorted in descending order and assessed for statistical significance. Our analysis uncovers substantial correlations in specific areas: notably, $PE.Excitement (r = 0.509, p < .001)$ and $EF.ProductionValue$ $(r = 0.506, p < .001)$. These strong correlations indicate that students with prior AlgoRythmics experience exhibit greater

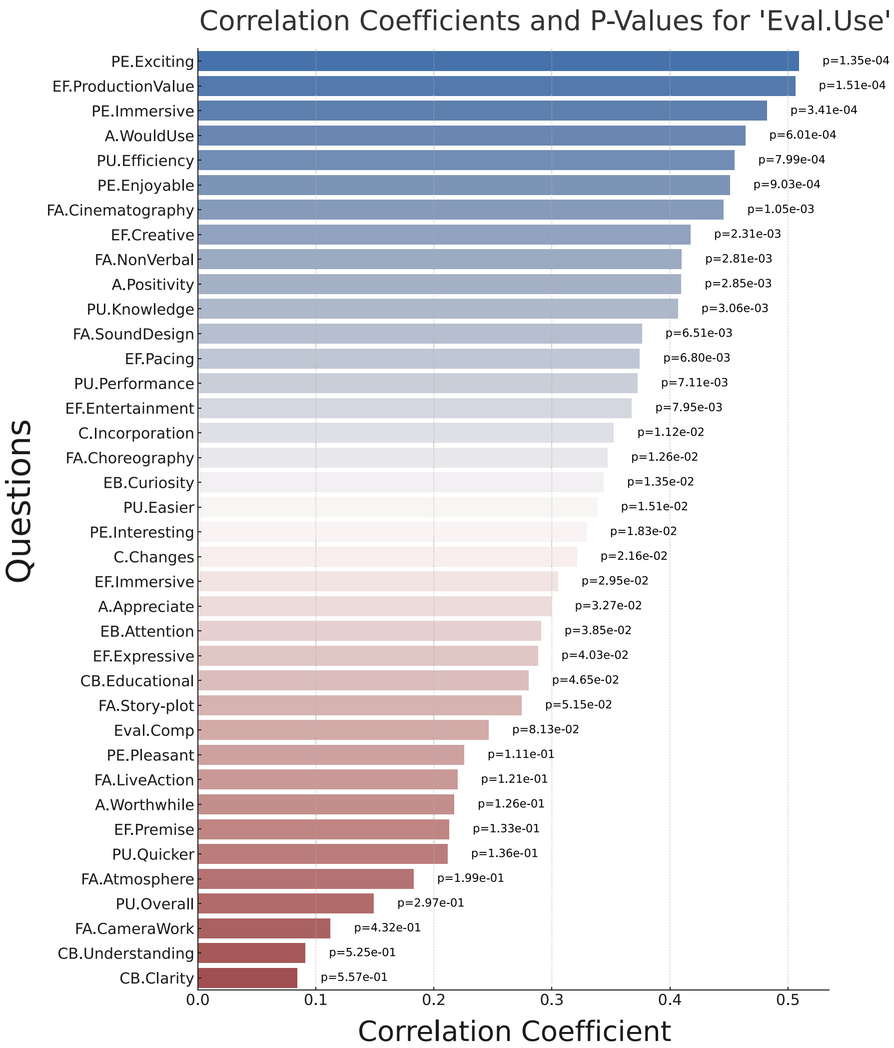

Fig. 6 Bar chart displaying the Pearson correlation coefficients (r values) between students' prior exposure to AlgoRythmics ($Eval.Use$) and different evaluation metrics of the educational movie

appreciation for these aspects of the movie. Similarly, significant correlations were found in the immersiveness of the learning experience ($r = 0.482$, $p < .001$) and the alignment with students' learning habits ($r = 0.466$, $p < .001$). These students also consider, that this format can help them get the most out of their time while learning, $PU.Efficiency$ ($r = 0.464$, $p < .001$).

Further, smaller yet significant correlations are observed in factors such as $PE.Enjoyment$ ($r = 0.451$, $p < .001$) and the perceived importance of cinematography ($FA.Cinematography$, $r = 0.446$, $p < .001$), suggesting a lesser but still noteworthy positive impact of prior exposure.

Conversely, the correlations within the Cognitive Benefits dimension, specifically $CB.Understanding$ ($r = 0.091$, $p = .525$) and $CB.Clarity$ ($r = 0.084$, $p = .557$), along with the general perceived utility of the format ($PU.Overall$, $r = 0.149$, $p = .296$), were weak and not statistically significant. This indicates that the perceived educational benefits of the movie, in terms of enhancing understanding of the subject matter and clarity of algorithmic strategies, does not significantly depend on prior exposure to AlgoRythmics content.

6.5 Structural equation modeling

The consistent Partial Least Square Structural Equation Modelling (PLSc-SEM) (Dijkstra & Henseler, 2015) algorithm is a statistical method used to analyze the relationships between latent (unobservable) constructs and their measured indicators. It is particularly well-suited to deal with situations such as ours, where the number of observations is limited (Reinartz et al., 2009), there are multiple sources of measurement error, and the underlying factors are reflective (i.e., they are measured by multiple indicators that are assumed to reflect the underlying construct).

PLSc-SEM is based on partial least squares regression, which involves creating latent variables (also known as components) that explain the maximum amount of variance in the observed data. The algorithm then estimates the relationships between the latent variables and their measured indicators, while taking into account the measurement errors associated with each indicator.

The "consistent" aspect of PLSc-SEM refers to its ability to adjust for any inconsistencies or redundancies in the correlations between the observed indicators of each reflective construct, so that the results are consistent with a factor-model. This is done by iteratively adjusting the estimates until they converge to a stable solution.

6.5.1 Validity and reliability

It is important to assess construct validity and reliability to ensure that the studied model accurately captures the constructs of interest, and that the results obtained are reliable and robust. In this section, we discuss the assessment of construct validity and reliability in our study.

Internal consistency, which measures the extent to which items within a construct are correlated, is commonly evaluated using the Cronbach's alpha coefficient, especially when Likert scales are employed. A recommended threshold for exploratory or pilot studies is a reliability score of 0.70 or higher. Scores ranging from 0.50 to 0.70 indicate moderate reliability, while scores of 0.50 or below indicate low reliability (Sideridis et al., 2018).

Additionally, composite reliability, another measure of internal consistency based on factor loading analysis, is often utilized. It ranges from 0 to 1, with higher values indicating greater internal consistency. Typically, a composite reliability score of 0.70 or higher is considered acceptable, while a score of 0.80 or higher is desirable (Tentama & Anindita, 2020).

Table 5 provides a summary of the reliability metrics for our constructs. It is important to note that Cognitive Benefits and Compatibility demonstrate moderate internal consistency, indicating some room for improvement in terms of the reliability of these constructs. However, all other constructs exhibit high or excellent reliability scores, suggesting that the measures used for these constructs are consistent and reliable.

The discriminant validity of the concepts was assessed using the Heterotrait-Monotrait (HTMT) ratio (Henseler et al., 2015) of correlations. This metric computes the ratio of the correlations between the items measuring different constructs (heterotrait) and the correlations between items measuring the same construct (monotrait). The HTMT ratio also ranges from 0 to 1, with values closer to 0 indicating stronger discriminant validity (i.e., lower correlations between items measuring different constructs) and values closer to 1 indicating weaker discriminant validity. The HTMT ratio is more robust to non-normality and small sample sizes than traditional methods such as the Fornell-Larcker criterion. A recommended threshold for the HTMT ratio is 0.90 (Gold et al., 2001; Teo et al., 2008), although some researchers argue that a more conservative threshold of 0.85 should be used (Clark & Watson, 1995; Kline, 2015).

The HTMT ratios presented in Table 6 provide valuable insights into the discriminant validity of the constructs in our model. All the HTMT ratios were below the commonly accepted threshold of 0.9, indicating a generally acceptable level of discriminant validity. The ratios range from 0.334 and 0.34 in the case of Filmic Attributes <->Perceived Utility and Engagement Benefits <->Cognitive Benefits to higher values of 0.847 and 0.854 for Perceived Enjoyment <->Engagement Factors respectively Filmic Attributes <->Engagement Factors. These higher ratios suggest a weaker dis-

Table 5 Reliability of the constructs

Construct	Cronbach's alpha	Composite reliability
Attitude	0.749	0.75
Cognitive Benefits	0.615	0.965
Compatibility	0.631	0.784
Engagement Benefits	0.765	0.774
Engagement Factors	0.834	0.842
Filmic Attributes	0.852	0.869
Perceived Enjoyment	0.896	0.903
Perceived Utility	0.878	0.896

Table 6 Discriminant validity: Heterotrait-monotrait ratio statistics (HTMT)

Construct pairs	HTMT
Perceived Utility <->Filmic Attributes	0.334
Engagement Benefits <->Cognitive Benefits	0.34
Perceived Utility <->Engagement Benefits	0.343
Perceived Enjoyment <->Cognitive Benefits	0.349
Cognitive Benefits < − >Attitude	0.38
Engagement Benefits <->Compatibility	0.387
Filmic Attributes <->Compatibility	0.398
Filmic Attributes <->Cognitive Benefits	0.427
Perceived Enjoyment <->Compatibility	0.435
Perceived Utility <->Perceived Enjoyment	0.534
Filmic Attributes <->Attitude	0.539
Perceived Utility <->Cognitive Benefits	0.543
Engagement Factors <->Cognitive Benefits	0.545
Engagement Factors <->Compatibility	0.563
Engagement Factors <->Attitude	0.576
Engagement Benefits <->Attitude	0.593
Perceived Utility <->Engagement Factors	0.598
Perceived Utility <->Attitude	0.664
Compatibility <->Attitude	0.679
Compatibility <->Cognitive Benefits	0.684
Perceived Enjoyment <->Engagement Benefits	0.69
Filmic Attributes <->Engagement Benefits	0.709
Perceived Enjoyment <->Attitude	0.762
Perceived Enjoyment <->Filmic Attributes	0.8
Engagement Factors <->Engagement Benefits	0.808
Perceived Utility <->Compatibility	0.845
Perceived Enjoyment <->Engagement Factors	0.847
Filmic Attributes <->Engagement Factors	0.854

criminant validity between these constructs, indicating that certain items or indicators within Engagement Factors and Filmic Attriibutes are capturing similar aspects of the underlying construct.

6.5.2 Bootstrapping

Bootstrapping (Davison & Hinkley, 1997) is widely used in PLS-SEM to evaluate the significance of the relationships between latent variables and to test hypotheses about the model's theoretical framework. The method randomly draws samples with replacement from the original data set to create multiple subsamples of the same size as the original data set. The model is then re-estimated for each subsample, and the estimates are averaged across all subsamples. The procedure produces two types of results: point estimates and standard errors. Point estimates represent the magnitude and direction of the relationship between variables, while standard errors indicate the precision of the estimates. The standard errors then can be used to test hypotheses about the significance of the relationships.

In this study we applied a bootstrapping procedure with 10000 subsamples and used it to assess the significance of estimated path coefficients in the model. Figure 7 presents the obtained results. On the arrows we see the β path coefficients with the p values in parentheses and the node of the Attitude construct we have the coefficient of determination R^2 (correlation between the observed and predicted values of the dependent variables).

The model explains almost three quarters of the variance in Attitude and all path coefficients are significant at the $p < .001$ level. Compatibility serves as an intermediate link in the causal chain between TAM constructs and Attitude. It mediates the relationship of the Perceived Utility and it also has a moderating effect on the relationship between Perceived Enjoyment and Attitude. The Engagement Factors have a positive effect on Perceived Utility through the Engagement and Cognitive Benefits. In the model, the Perceived Enjoyment is mostly determined by the Filmic Attributes.

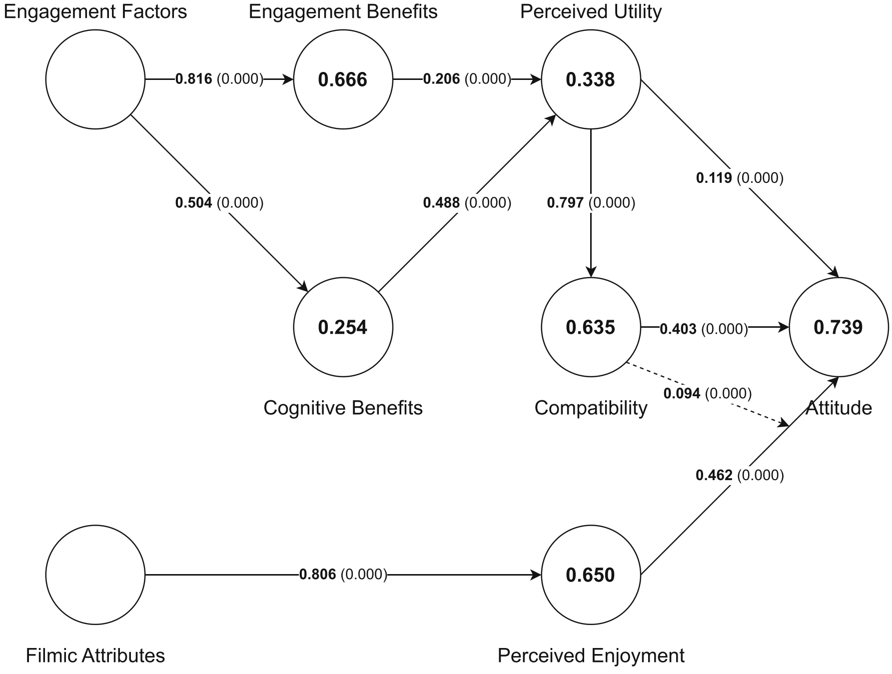

Fig. 7 PLS path model with estimated parameters

7 Discussion

The present study marks a significant advancement in research focused on guiding AlgoRythmics storytelling. In this study, we introduced the term 'enacting algorithms' as a replacement for 'dancing algorithms'. Our investigation specifically involved analyzing student feedback on a novel tool suitable for depicting the intricacies of complex algorithms. To demonstrate various algorithmic strategies, we showcased a short film in the classroom that portrayed three approaches: ad-hoc, greedy, and dynamic programming. For data collection, we designed a questionnaire based on an extended version of the TAM, encompassing three key factors: perceived utility, perceived enjoyment, and compatibility. In addition to these constructs, we also examined the influence of contextual and technology-specific factors, including cognitive and engagement benefits, as well as filmic attributes, on user attitude, including adoption intention.

In evaluating the analyzed educational tool, it is crucial to highlight that all respondents reported perceiving an educational benefit, underscoring the effectiveness of the chosen method. This outcome signifies that the inclusion of cinematic elements did not diminish the educational content, but rather emphasized it. Put differently, the incorporation of cinematic elements successfully facilitated an engaging learning experience without compromising the educational aspects. This outcome aligns with the fundamental requirement of any educational aid, where both educational value and engagement are essential components (Höffler & Leutner, 2007).

This result is particularly promising, especially in light of the concerns raised in previous research regarding distracting elements within AlgoRythmics dance choreographies (Katai & Osztian, 2022). In folk dances, there is a tendency for predefined movements, which can pose challenges when attempting to align them with the algorithmic content. In accordance with this, De Koning and Tabbers (2013) emphasize that observing unrelated or unnecessary gestures has the potential to hinder the processing of activated schemas and divert attention away from vital information crucial for effective learning. In contrast, in staged scenes, choreographers have greater freedom to adapt the movements to align with the instructional content and exercise control over potentially distracting elements. This greater control over choreography allows for a more seamless integration of the algorithmic concepts, minimizing distractions and enhancing the learning experience.

Nevertheless, divergent opinions emerged regarding specific filmic aspects of the tool, with the immersion factor receiving the highest percentage of neutral responses. This finding underscores the difficulty in creating captivating short films for effectively conveying CS content. However, despite these challenges, the overall positive evaluation of the tool can be attributed to the students' perception of its concept as highly innovative. Notably, the $EF.Creative$ component garnered the highest percentage of "strongly agree" responses (over 50%), indicating the students' recognition of its originality and creativity. Additionally, the significant student appreciation for the live-action component reinforces the effectiveness of incorporating human movements in dynamic visualization, while the positive feedback regarding cinematography and expressiveness elements suggests that utilizing cinematic representations to illustrate algorithms holds promising potential.

The previous research on the HME has predominantly concentrated on its direct cognitive impact on the learning process, often in relation to Cognitive Load Theory (Sepp et al., 2019). However, the current study introduces a new perspective by examining students' appreciation of the live action component in the cinematic short film. Live action performances, in contrast to animations, have the ability to establish a social and emotional connection between performers and learners (Han et al., 2023). The presence of real individuals engaging in movement evokes emotions, inspires, and captivates learners in ways that generic human movement may not achieve. This emotional connection has the potential to enhance motivation, engagement, and overall learning outcomes. This highlights the importance of considering the social and emotional aspects of HME and its potential contributions beyond cognitive factors. Further exploration of these dimensions can provide valuable insights into designing effective educational interventions that incorporate live action components.

Furthermore, the heatmap depicted in Fig. 5 provides additional insights into the complex relationships among the analyzed dimensions. On one hand, it unveils a strong consistency in students' perceptions across the dimensions of Perceived Enjoyment and Perceived Utility. On the other hand, the observed pattern of moderate intercorrelations among the relatively distinct dimensions of Perceived Enjoyment, Engagement Factors, and Filmic Attributes indicates that Perceived Enjoyment is more than just a solitary affective response. Instead, it intricately intertwines with students' perceptions of engagement and aesthetic appeal in the evaluated movie.

The role of attitude within the TAM is pivotal (Kasilingam, 2020), and the high agreement load obtained for this construct in our study holds great promise. Our SEM analysis further revealed significant contributions from both Perceived Usefulness and Perceived Enjoyment components to this level of appreciation. Notably, Compatibility exhibited both mediating and moderating effects. This aligns with prior research that has also substantiated the significance of the Compatibility factor (Agag et al., 2019). For instance, Chiu et al. (2016) identified Compatibility as a key mediating element between Perceived Usefulness and actual use. Similarly, Vishwanath and Goldhaber (2003) indicated that individuals' attitudes, which are shaped by their perceptions of compatibility and observable use, influence their intentions to adopt new technologies.

Moreover, our results indicate that the indirect influence of Perceived Usefulness on Attitude, mediated by other factors, was more substantial than its direct effect. Additionally, Compatibility enhanced the impact of Perceived Enjoyment on Attitude. While a majority of the students perceived the method under study as useful, those whose learning styles were more compatible with this approach exhibited a stronger association between Perceived Usefulness, Perceived Enjoyment, and Attitude. These findings underscore the importance of factoring in Compatibility and individual learning preferences when studying Attitude within the framework of the TAM. Such considerations can profoundly influence users' perceptions and technology acceptance behaviors.

The significance of Compatibility is evident in the students' feedback on the past utilization of AlgoRythmics dance choreographies ($Eval.Use$ item). Notably, this item received a higher percentage of negative (18%) and neutral (20%) evaluations compared to the other items. A prior AlgoRythmics study (Katai, 2020) demonstrated a 96% positive global evaluation ("I liked this e-learning session") for a learning session incorporating an algorithmic dance choreography. Additionally, the evaluation for the item "I liked this e-learning session because of the dance" was 97%. In contrast, the $Eval.Use$ component received a positive load of only 63%, significantly lower than these values.

The analysis presented in subsection 6.4 offers additional insights into this matter, revealing a significant association between the utilization of previous AlgoRythmics videos and an enhanced appreciation for specific aspects of the movie. Moreover, these correlations extend beyond the aesthetic elements of the film, encompassing the immersiveness of the learning experience and compatibility with students' learning habits.

These findings suggest, on the one hand, that students who have incorporated AlgoRythmics videos into their learning journey tend to experience increased enjoyment with the presented educational movie and assign greater significance to cinematography. On the other hand, this analysis also revealed that perceived educational benefits associated with understanding the subject matter and the clarity of algorithmic strategies may not strongly depend on prior exposure to AlgoRythmics content. The encouraging aspect is that these perceived educational benefits are not contingent on prior use of the AlgoRythmics content, highlighting the positive implications of our examination of the current educational tool.

Again, this phenomenon may be attributed to the fact that although students enjoy the learning experience, they may not use the approach on their own in the future, as it is not compatible with their learning habits. However, we believe this should not be a major concern in our case as we focused on the effects of a one-time application of a short film representation by the teacher. The fact that students genuinely enjoyed the class is a significant educational achievement. Furthermore, it is encouraging to note that, despite the reservations expressed regarding the use of dance choreographies (63% positive load), the respondents displayed a much more positive attitude towards the comparative advantages of a short film representation ($Eval.comp$: 83% positive load).

In conclusion, despite the considerable initial investment of time, effort and creative work needed to plan, coordinate and execute a compelling algorithm enactment in filmic form, the feedback received offers promising outcomes, indicating that the benefits derived from this initial investment are substantial. Once the cinematic depiction is produced, it can be perpetually reused, further amplifying its long-term value and impact.

7.1 Limitations

The effectiveness of the proposed tool and method was assessed on a limited number of students, and only two algorithmic strategies were utilized to address a specific computer science task, which may limit the generalizability of the findings. Also, the interrelationships among the observed variables were not explored, which could provide a more nuanced understanding of the factors that influence the effectiveness of the cinematic approach. Lastly, a more comprehensive analysis of the significant findings pertaining to compatibility and attitude is required to gain deeper insights into the potential mechanisms underlying the observed effects. Future research must address these aspects to provide a more complete understanding of the potential benefits and limitations of using cinematic depictions for teaching algorithmic content and programming concepts.

Furthermore, to enhance our grasp of the effectiveness of the short film approach, we plan to undertake a comparative analysis. This will involve the inclusion of a control group and a direct comparison of the film's efficacy with traditional teaching methods, specifically focusing on learning outcomes. Adopting this approach may help mitigate potential biases that could have influenced the current investigation, such as the halo effect and confirmation bias.

8 Conclusions

The present research represents an extension of the AlgoRytmics concept to encompass more complex algorithms, specifically greedy and dynamic programming techniques. A novel aspect of this study is the departure from traditional dance choreographies, opting instead for cinematic scenes to illustrate the selected CS concepts. This new approach aims to maintain two key strengths of the previous AlgoRytmics videos: the activation of the HME and the ability to generate interest through unexpected art-science combinations. Simultaneously, it leverages the remarkable potential inherent in cinematic storytelling. More specifically, our study investigated the educational efficacy of employing cinematic portrayals, featuring actors enacting algorithmic content, to enhance learning outcomes.

Student feedback was gathered through a questionnaire that evaluated the perceived utility, enjoyment, compatibility, filmic and engagement factors, as well as self-assessed attentional and cognitive benefits. The results showed that students found the short film to be useful, enjoyable, engaging, and to have positive cognitive and motivational effects. The cinematic elements were able to enhance the learning experience without detracting from the educational value. Moreover, a SEM analysis revealed that these favorable evaluations are particularly evident in the attitudes of students whose learning habits align with the method and tool under investigation. In addition, results highlight the significance of recognizing the motivational dimensions associated with incorporating acting movement in visualization tools and acknowledging its potential contributions that extend beyond cognitive factors.

Overall, the findings of this study provide valuable insights into the effectiveness and potential benefits of employing cinematic depictions and acting movement in CS educational settings, opening avenues for future research and development in this field.

Funding Open access funding provided by Sapientia Hungarian University of Transylvania.

Data Availability The dataset generated and analyzed during this study is available in Figshare with the identifier https://doi.org/10.6084/m9.figshare.25053356.

Declarations

Conflicts of interest The authors declare that they have no conflict of interest.

Ethical approval This study was approved by the university human research ethics committee and all procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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