A Storytelling Platform for Deeper Learning in STEM Combined with Art-Related Activities

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Abstract: - The STORIES storytelling platform provides the means and the tools along with the necessary collaborative and personalization functionalities to introduce students and monitor their performance in extended episodes of deeper learning in Science, Technology, Engineering, and Mathematics (STEM) combined with art-related activities (visual and performing arts, music, movie making, 3D design). The platform introduces students in a progressive exploration of the different technologies that can be

accommodated from the system, from simple text and video uploading to advanced augmentations of students' artifacts.
Key-Words: - Storytelling, Collaborative, STEAM, STEM, Authoring, Virtual Reality, Augmented Reality, Problem Solving, Deeper Learning.

1 Introduction

The STORIES storytelling platform is specifically designed for teaching professionals in STEM disciplines (Science, Technology, Engineering, and Mathematics). It introduces teachers to the concept of digital storytelling as well as inquiry-based science teaching techniques to develop, improve and enhance their teaching skills and practices. It is an advanced storytelling platform enriched with innovative interfaces (VR and AR) to support students' creations. The creations of the students (paintings, models, dioramas and constructions, 3D objects and landscapes, animations, science videos and science theatre plays) are captured according to their scenarios and are integrated in storylines. The storylines are available in the form of e-books while advanced interfaces (3D Worlds, VR and Augmented Reality) are offered to bring students stories in life.

In this work, we start by presenting the pedagogical background behind the platform. In the third chapter we are presenting the different components of the storytelling platform and in the Fourth one, the technical architecture. In Chapter 5 the main technologies of each component are described and in chapter 6 the challenges we faced during implementation.

The STORIES platform is result of Stories of Tomorrow project that is a research and development project funded by the European Commission (Horizon 2020, project No. 731872), involving 15 project partners from 10 countries.

2 Pedagogical Approach

2.1 Creative STEM Education

The STORIES approach is based on the integration of arts into STEM activities, simulating the ways in which subjects naturally connect in the real world. The STORIES pedagogic principles are ultimately employed in order to help learners and adult professionals imagine new ideas in STEM education; to shift from "what is" to new possibilities of "what might be".

In the heart of STORIES approach we find WHC (wise humanizing creativity) and LDS (living dialogic space). The WHC that is being sought in STORIES is not only an individual activity, but also happens in collaboration with fellow learners, teachers and other adult professionals (artists, researchers, space experts). These individual and collaborative creative activities form part of a wider web of ethically-guided communal interaction geared towards both helping children and young people become more creative and assisting teachers in becoming more creative in how they teach science. Alongside and integrated with WHC, is LDS, always a partner to WHC in terms of conceptualizing ideas and developing practice. LDS methods (participation, emancipation, working bottom up, debate and difference, openness to action, partiality, and acknowledging embodied and verbal modes of knowing) are fundamental to allowing WHC to happen. Chappell et al [1], have evidenced the importance of dialogue at the heart of engaged, creative learning in the arts and it is this kind of dialogue that has been highlighted and applied within the STORIES approach. Students' stories promote the idea of dialogue between people, disciplines, creativity and identity, and ideas. This dialogue acknowledges and allows for conflict and irreconcilable difference. So, via these processes STORIES contribute to developing creative young minds with deep knowledge in STEM and creative STEM teaching pedagogies.

2.2 Storytelling in the 21st century classroom

According to Jenkins et al [2], digital storytelling is one mode of twenty-first century learning [3]. Digital stories derive their power by weaving images, music, narrative and voice together, thereby giving deep dimension and vivid color to characters, situations, experiences, and insights [4].

With the current expansion of digital tools and on advanced interfaces, the media and the tools used for narrating are changing [5]. Scholars in the field of media and education have found that "digital storytelling in many ways (helps) to support students' learning by encouraging them to organize and express their ideas and knowledge in an individual and meaningful way" [6]. Digital stories have proven to be a powerful medium to express their voice with intellectual depth in a form other than writing [7]. Meaningful engagement in literacy in which students can invest their identities are

crucial in today's linguistically and technologically diverse world. Research findings demonstrate that students who were involved in storytelling activities were active architects of their own understanding [8] while creating a digital story consists of using a mixture of visual, gestural, auditory and linguistic skills [9]. Barrett [10] found that digital storytelling facilitates the convergence of four student-centered learning strategies: student engagement, reflection for deeper learning, project-based learning, and the effective integration of technology into instruction [11].

2.3 Enabling Technologies

While technology alone may be engaging and motivating, deep and lasting learning certainly requires more than just exposing students to such innovations. The way that innovative and meaningful pedagogies are utilized to create engaging and creative learning experiences supported by technologies is the key. Dubbed "authentic learning", student-driven inquiry (e.g., through problem- or project-based approaches) is seen as being able to engage learners more deeply on more complex tasks than other types of pedagogy. More and more, research not only demonstrates that student-inquiry leads to lasting learning and higher performance, but it also points out that pedagogical approaches based on problem-solving and critical thinking are necessary for them to access 21st century skills as well as cultivate creativity [12]. While technology is certainly not mandatory in order to implement this kind of pedagogy, it most certainly helps, and in three distinct ways: tools, means, and mechanism. The STORIES Storytelling Platform is an excellent example of this. An online environment where students can organize their own learning and work, the can also collaborate with others around a problem or project and collectively grow the knowledge and outputs that define a true "community of learners". STORIES technologies provide the storyline or context upon which the project and inquiry are structured. Augmented reality applications, online simulations and many other technologies provide mechanisms for structuring inquiry-based learning in a very engaging, and relevant, way.

3 STORIES platform

The STORIES Storytelling Platform is built upon Q-Tales storytelling components [13, 14] which were further developed and customized in order to serve the STORIES pedagogical framework. The Students can create stories, consisting on different episodes taking place in different settings (Earth, Space, Mars). Each episode can be enhanced with 3D and augmented reality tools. The platform is the result of the integration of different components that are all orchestrated to offer the STORIES experience to the students. All of them are interconnected through an Application Programming Interface (API). These are: (a) the Collaboration platform as entry, and single sign on, point, (b) the STORIES Authoring tool and main player where the students can create their stories, (c) the advanced authoring tools for sending rockets and building colonies on mars, (d) the augmented reality tool for adding augmentation to stories, and the (e) business intelligence analytics system for evaluating students' achievements.

3.1 STORIES Collaboration Platform

The Collaboration Platform contains the main web interfaces available to students, teachers, experts, administrators and parents. It monitors the students' progress and engagement with the different tools of the system. The collaboration platform is the entry point to the STORIES ecosystem. The users can login through this tool and create other users, based on their role and authorizations.

Fig. 1. Stories Collaboration Platform

The collaboration platform is developed in PHP using the Symfony 2 MVC Framework. The core database -the database that is responsible for the functionality of the entire collaboration platform- is a MySQL Ver 14.14 Distrib 5.7.19. The Object Relational Mapper (ORM) used for the communication between the PHP code and the database is the Doctrine Project. A RESTful API is developed to ensure the secure communication between the Collaboration platform and the rest of the STORIES components (authoring tools and players). This Collaboration API is the tool that handles the execution of all the communication

protocols, the synchronization and the data transfer among all components; it also implements and monitors the main security mechanisms. The Application Programmable Interface (API), which is used for the secure data transfer and the synchronization of the various components, is also written in PHP using a Symfony 2 MVC framework and complies with all the architectural guidelines and best practices of a RESTful API.

3.2 STORIES Authoring Tool and Player

The Stories Authoring tool is available in every episode of a students' story. It's the main tool for the students to setup and present their work and the link to the other STORIES modules (3D Rocket, 3D Colony and AR content development). Each story can have numerous episodes of different types. Apart from the cover of the story, the 3 different types of episodes are: (a) Earth episodes that the students can add 3D Rockets and AR to their stories, (b) Space episodes that the students can add AR to their stories, and (c) Mars episodes that the students can build 3D Colonies and add AR to their stories.

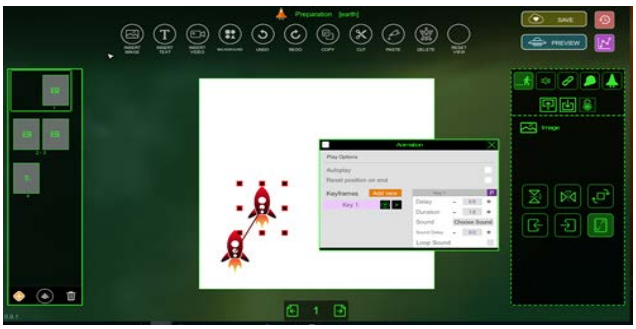

Fig. 2. Stories Authoring Tool

The authoring tool and players are based on Unity game engine (https://unity3d.com/). Unity with its 5.3 version (December 2015) made WebGL support official. WebGL is a JavaScript API for rendering interactive 3D computer graphics and 2D graphics within any compatible web browser without the use of plugins. WebGL programs consist of control codes written in JavaScript and special effects codes (shader codes) that are executed on a computer's Graphics Processing Unit (GPU). WebGL elements can be mixed with other HTML elements and composited with other parts of the page or page background. Unity's exporters work for WebGL by taking a runtime written in native (i.e. C/C++), and cross-compiling it to asm.js + WebGL via Emscripten that is an LLVM (Low Level Virtual Machine)-based project that compiles C and C++ into highly-optimizable JavaScript in asm.js format. This lets users run C and C++ on the web at near-native speed, without plugins.

3.3 STORIES 3D Authoring tools

The 3D authoring tools consist of a tool for having the students able to build their own colonies on Mars, and a tool that gives the ability to students to create their 3D Rockets and load them with the objects they want to send to Mars to build their colonies. The two modules (3D Rocket authoring and Colony Authoring) are logically connected, and the students are able to build their colony, only if they have sent a rocket with the desired objects, and only if they have sent them in the correct place on Mars. With 3D Rocket authoring tool, the rockets can be built with some external 3D applications (e.g. Tinkercad). It's then very easy for students to import their preferred rockets in the STORIES platform.

Fig. 3. 3D Rocket Authoring Tool

Fig. 4. 3D Colony Authoring Tool.

A colony simulator runs all the time to evaluate the sustainability of the colony that the students build. The evaluation is done through a list of rules set by experts. Object categories have some global properties (common for all objects in the category) as well as custom object properties added by the experts. Same object property can belong to more than one objects instances (e.g. power consumption) belonging to different object categories. Finally, there are the rules that contain formulas for measuring specific properties and combination of property values within a colony.

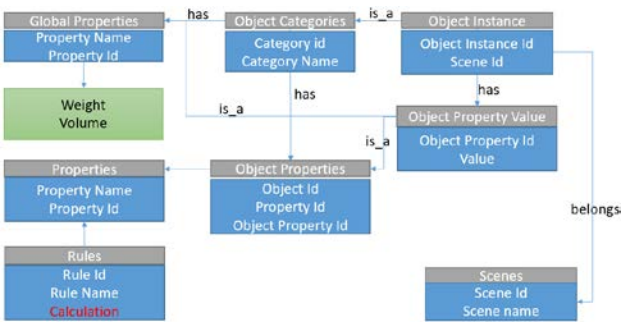

Fig. 5. 3D Objects, their connected Properties and Rules Diagram.

A rule consists of three parts. The left and right side are the formulas and the middle component is a comparison operator (>, <, =, <>). The result of each rule is true or false. The mathematical operations for the formulas (left and right parts of a rule) that the tool currently supports are addition, subtraction, division, multiplication and parentheses. Each formula consists of combination of expressions. The first part of an expression is the category that the property applies. This means that it can either be a [Category Name] or the keyword GLOBAL. GLOBAL stands for every object in the colony that contains this property. The second part of an expression is the name of the property as inserted in the system. The third part of an expression is a function. The functions can take one of the following values corresponding to the relevant mathematical computations: (a) Average - AVG, (b) Summation - SUM, and (c) Count- COUNT. For example, the expression GLOBAL.POWERCONSUMPTION.SUM is the summation of the power consumption of all the objects within the colony. The SOLARPANEL.POWERPRODUCTION.AVG expression is the average power production of all SOLARPANEL objects within the colony.

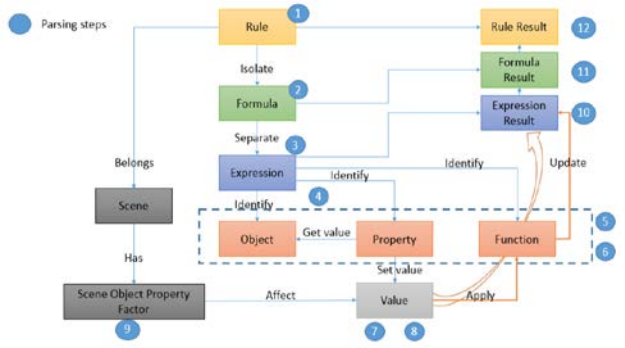

Fig. 6. Stories Parser for checking the validity of the rules

The relevant parser for the rules evaluation follows the steps in the following order (fig 6):

1). Parser starts with a rule and reads the two formulas (left and right part) and the comparison operator.

2). Both formulas are parsed and the expressions inside are detected and isolated in a separate list.

3). The parser creates a list of pairs. The first part of a pair is the expression in text format and the second is the value that will be calculated.

4). Each expression is parsed and broken down in parts. The first part of each expression is checked in correspondence to the list of object categories loaded from the server. The second part is checked in correspondence to the list of properties loaded from the

5). server. The third part is checked in correspondence to the list of functions.

6). If any of the above parts is not found within its corresponding list the whole expression is ignored and a message is shown to the user.

7). If the expression is valid the parser gets all objects from the colony corresponding to the first part of it.

8). The parser continues to load the property mentioned in the expression from each of the received objects.

9). The parser checks for scene parameters that affect property values and update values accordingly.

10). At the end of each expression the parser uses the function corresponding to the third part of it and returns the result to the list created in step 4.

11). When all expressions are calculated the expressions in the formula are replaced with their result and each formula is calculated (for being true or false).

12). The parser checks if the rule is true or false and shows the result to the user.

In fig 7 a diagram illustrates an example of how the parser works. The formula is initially split by contained delimiters (+, -, *, /). Then each part derived is split again with the (".") in three parts corresponding to Object Category, Property and Function. The value of each part is replaced in the initial expression and the value of the expression is calculated.

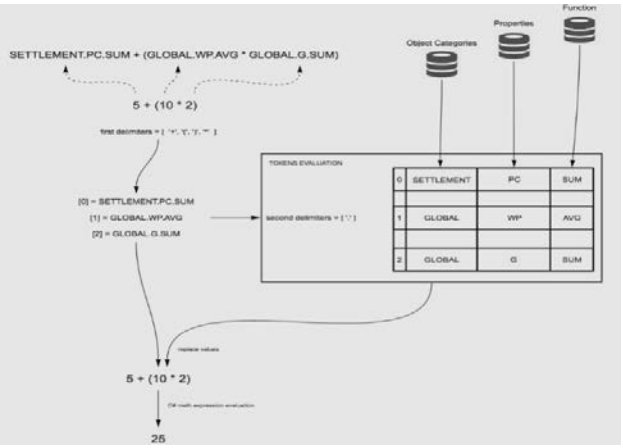

Fig. 7. An example how the parser works.

3.3 STORIES AR tools

The main idea behind AR in STORIES is that students are able to create their own Augmented Reality elements and incorporate them into their stories, to be then visualized by the rest of the schoolmates, teachers and parents. The STORIES AR Tools consist of two modules: (a) the AR Authoring Tool, that is a web-based platform where students can create their own Augmented Reality contents to include in their stories. This tool is integrated into the overall STORIES platform and communicates with the API to retrieve/send the pertinent information, and (b) the AR Viewer that is the mobile app where any user is able to see the AR contents created for a particular story. The possibility of displaying extra information such as explanations, videos, 3D representations or animations over real objects makes Augmented Reality a valuable asset for educational projects. It has proven successful on visualizing concepts that users cannot detect with their own senses, e.g. magnetic fields or electric currents and signals [15] [16] and it is also being used in medical fields such as anatomy where information coming from real patient's scans can be superposed over real or 3D printed body parts [17].

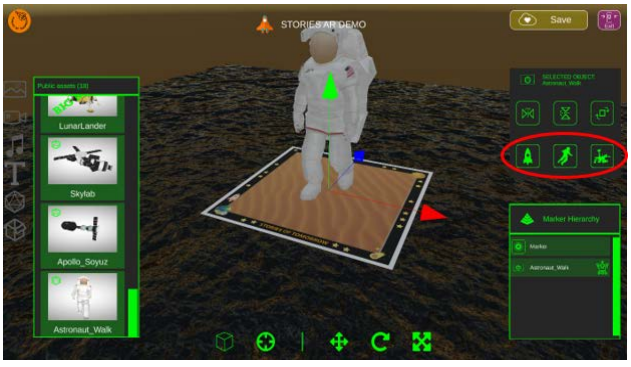

Fig. 8. Stories AR Authoring Tool

Vuforia [18] in combination with Unity game engine is used as the main AR engine in STORIES. Its main strengths include the best recognition stability, largest recognition distance, and a wide variety of pattern and image recognition. It is also one of the most used SDKs and compatible with Unity3D. Vuforia works both on Android and iOS and has lately developed support for Windows 10 and a variety of glasses such as Moverio BT200 or Hololens [19], [18].

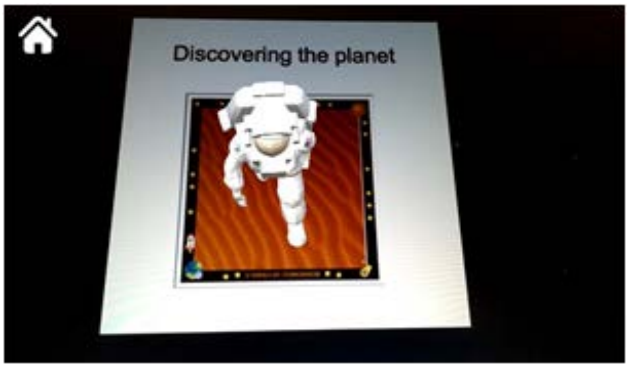

Fig. 9. Stories AR Player

In the AR Authoring Tool students first select the image they want to use as the marker and then, all the contents (images, audio files, videos, texts or 3D models) that are going to appear over that marker. They can edit and customize those contents and when they finish, they only have to include the created marker in their story through the STORIES Authoring Tool.

Any user will then be able to visualize the AR elements using the AR Viewer app and pointing with the camera to the marker.

One of the main challenges for the AR applications working on the browser is the management of the memory. Browser WebGL applications are very restrictive on the use of memory resources and heavy models tend to collapse the application. Initially the OBJ file format was selected because it is one of the most standardized formats but during the testing process of the tool, it was seen that the creation of the meshes in real time, sometimes require too much memory from the AR Authoring Tool. As an alternative glTF [20] was selected a format represented by JSON formatted files offering Compact file sizes, Fast loading, Runtime-independence, Complete 3D scene representation and Extensibility [21]. Considering that 3D model repositories such as Sketchfab [22] or Turbosquid [23] count on 100,000+ models under Creative Commons license in glTF format or that 3D modelling tools such as Blender, 3D Max or Maya already export to glTF, the use of this format for the

3D models has been considered the best alternative for the AR Authoring Tool. In addition, glTF format allows custom embedded animations on the models. Currently, the AR Authoring Tool and Viewer support both the OBJ and glTF formats to give users a wider range of options. Online converters such as [22] also make it easier to go from one of the formats to the other.

3.4 E. STORIES Analytics tools

Stories intelligent server analytics is an integrated dashboard tool interface, which includes the following data categories: (a) general analytics (schools, students, stories, episodes, etc.), (b) evaluation analytics, (c) collaborative [PRE] questionnaire analysis, (d) collaborative [POST] questionnaire analysis, (e) fascination [PRE] questionnaire analysis, (f) fascination [POST] questionnaire analysis, (g) knowledge [PRE] questionnaire analysis, (h) knowledge [POST] questionnaire analysis, (i) Authoring tool analytics, (g) Google Analytics for the integrated platform. [PRE] categories include data on students' achievements before schools' using STORIES platform, while [POST] categories include data on students' achievements after schools' have used it. Each category includes subcategories of charts and reports which help users to depict the desired information either graphically or analytically. Most charts display the corresponding information per country or per school participated, based on the criteria user selected. The Stories server analytics engine and dashboard were built using Java and Angular software technologies.

3 STORIES architecture

The STORIES Ecosystem is divided into layers on an N-tiered architecture. Some of the components spread vertically through the various tiers such as the DRM mechanisms and the Security modules and others spread through all the components of a specific tier. Such an example being the ORM which sits over the entire data tier to act as a middleware between the application and the data tier.

The Presentation Tier includes: (a) The front end of the Collaboration Tool, (b) The front end of the Authoring Tools, (c) The Story Player, (d) The Dashboard Analytics Tool, (e) User Clients (Smartphones, VR Headsets, PCs / Macs).

The Application tier includes: (a) The STORIES API – Web Services, (b) The 3D Worlds Building Module, (c) The Virtual Reality (VR) Player, (d) The augmented Reality (AR) Content Development Module and Player, (e) The STORIES Authoring Module and Player, and the (f) Analytics Engine.

The Data tier includes: (a) The data persistence mechanisms (database servers, file shares, etc.) and the data access layer that encapsulates the persistence mechanisms and exposes the data to the Application Layer, (b) The ORM and Third-Party Data Integration mechanism expose the methods of managing the stored data without exposing or creating dependencies on the data storage mechanisms. Avoiding dependencies on the storage mechanisms allows for updates or changes without the application tier clients being affected by or even aware of the change, and (c) A set of Databases (both relational and non-relational ones) needed by the Presentation layer.

4 STORIES technologies

4.1 Collaboration Platform

The collaboration tool component spans all tiers. It follows the MVC architecture, which is considered to be the best approach when designing web applications and is highly recommended when the data to be displayed are user-specific. The View and Controller parts of the MVC architecture are components of the presentation layer and of the front end of the Collaboration Tool, which comprises the user dashboard, detailed screens and controls thereof for user activity and inter-user messaging. A complex DRM (Digital Rights Management) mechanism and a complex Access Control algorithm are responsible for the security of all communications taking place through the Dashboard, the privacy of each user and the integrity of all data transferred.

4.2 Authoring Tools and Players

STORIES Authoring Tools are based on the Unity 3D game engine, but the user of the tools is not required to have Unity 3D platform installed, or any knowledge of Unity 3D in order to create a story. This is since all required functionality has been exposed to the authoring environment (WebGL), in a transparent manner, making the story creation extremely easy. It is the Authoring Tools through which the student is to build the story, including creating VR and AR content. The Authoring Engine encapsulates the business logic of authoring: it accesses the Stories Repository in order to retrieve

stories in progress and save current work; it uses Scientific Data both as visual cues to the student and as parameters to the models; and it utilizes the 3D Objects Repository in order to retrieve 3D objects to use.

4.3 User Client Apps for AR and VR

User client apps are device-specific applications that simulate, in a device-specific manner, the narration of stories produced by way of the Authoring Module. A mobile app for Android and iOS is developed for STORIES AR player and a standalone application for Windows PCs has been created for VR support using Oculus Rift.

4.4 Analytics Engine

The analytics comprise of a broad range of business intelligence capabilities, including viewing and administering dashboards, reports, scorecards, and events. They are mainly accessed through the web interface provided by the Dashboard Analytics Tool. The STORIES storytelling platform provide a full view of system activity as well as of the students' Deeper Learning Profiles, thresholds and other system metrics, so that Coaches as well as the research team get to have the information they need in order to resolve potential issues before there is a material educational impact.

4.5 STORIES API – Web Service

The STORIES API is a set of RESTful web services designed to transfer the required data from the Data Layer to Presentation Layer, while ensuring the integrity, the availability and accessibility of the requested resources. The API is responsible for all the communication and synchronization protocols in the STORIES Platform. The API is also responsible for the following mechanisms: (a) DRM System: The file system and the Data rights management mechanism, (b) User Management: Authentication, access list management, user role clearance levels, user group management, (c) Synchronization: Race conditions resolution, session management, and (d) Security: HTTP over SSL, Encryption, Master Key generation (Master Key is a unique key which holds all the information about a user and is used to personalize the responses by the Web Services).

4 Results

The STORIES platform was used in European schools from November 2017 till June 2018 (about 700 students or regular basis, mainly from Greece, Portugal and France). Based on the data from the implementation each story created by students includes 500 assets (pictures, videos). The students have logged in 500 times and they have exchanged 400 messages (interactions) for each story. In almost all cases the data indicate a significant increase to the collaborative problem-solving competence. This is supported from the collaborative approach for the story development and from the fact that numerous interactions were realised between students. In many cases there is significant increase in students' knowledge was reported. We expect the fascination to increase also in the second pilot round that the AR and VR tools will be offered to the students to integrate them in their stories.

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