A Secure and Practical Decentralized Ecosystem for Shareable Education Material

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***Abstract*—Traditionally, the university landscape is highly federated, which hinders potentials for coordinated collaborations. While the lack of a strict hierarchy on the inter-university level is critical for ensuring free research and higher education, this concurrency limits the access to high-quality education materials. Especially regarding resources such as lecture notes or exercise tasks we observe a high susceptibility to redundant work and lacking quality assessment of material created in isolation by individual university institutes. To remedy this situation, in this paper we propose CORALIS, a decentralized marketplace for offering, acquiring, discussing, and improving education resources across university borders. Our design is based on a permissioned blockchain to (a) realize accountable access control via simple on-chain license terms, (b) trace the evolution of encrypted containers accumulating bundles of shareable education resources, and (c) record user comments and ratings for further improving the quality of offered education material.**

***Index Terms*—blockchain platform; permissioned blockchain; education material; quality assessment; collaborative work**

I. Introduction

While universities have the common goal of providing high-quality education to form young experts, the university landscape is inherently federated and even a competitive environment regarding publications and available funding sources. This competitive aspect of research puts the modern university landscape under high pressure [1] and thus researchers find themselves in a dichotomy: A certain level of collaboration among mutually trusting institutes proves profitable to gain high-quality insights, but avoiding tight collaborations out of the fear of losing a lead over competitors has also been established as a rational approach. This dichotomy is especially apparent when taking the universities' duty to educate into account. Currently, there exists no clear incentive for universities to collaboratively create or improve education resources, such as lecture notes, slides, or exercise tasks. This status quo introduces a major drawback: Similar education material is frequently being created and maintained redundantly across different institutes, potentially even within one university. If institutes could instead invest this time into improving each others' education resources, we see a great potential for creating high-quality and highly vetted pools of education material from which all students could benefit equally. While individual contractual collaborations across university institutes [2] and education repositories of varying focuses [3] exist, those isolated approaches cannot unveil the full potential of globally available high-quality education material. However, a versatile range of education prospects is critical to properly prepare students and seize creative opportunities. Yet, these aspects are threatened by strong centralization in education [4].

Hence, in this paper we propose to create a *decentralized* ecosystem that incentivizes the collaborative creation, maintenance, and improvement of education resources. Distributed ledgers such as blockchain systems provide the means to create such an ecosystem despite the inherent trust barriers regarding inter-university collaborations. Popularized by Bitcoin and Ethereum, distributed ledgers constitute a general medium for the secure and accountable interaction of mutually distrusting parties [5], [6]. Our proposed blockchain-based platform, *CORALIS*, serves as a decentralized *index* of available education resources, provides a *marketplace* with accountable access control for these resources, and *incentivizes collaboration* across university borders to improve them. To achieve these desired properties, CORALIS relies on immutably recording all relevant events on its underlying permissioned blockchain: First, material providers, who can either be university teachers or accepted third-party content creators, announce new education resources in conjunction with simple and tunable license terms to the platform. Subsequently, users, i.e., other university teachers, interested in buying this material have to perform an on-chain handshake beforehand that immutably records both parties' mutual agreement to trade the material under the specified license terms. Finally, participants collaboratively improve existing resources by *rating* them, *discussing* flaws or improvements, and *proposing* improved versions of existing material, either to resolve issues or to provide extensions.

Contributions. We make the following main contributions to improve inter-university collaborations for creating and sharing education material in a practical and secure manner.

- We identify the need for a *decentralized* and *transparent* platform to enable universities to collaboratively maintain education material across university borders as well as the open challenges for such a ecosystem.
- We propose *CORALIS*, a design for a practical blockchain-based platform that enables material providers to securely share their material.
- We discuss approaches for *licensing shareable education resources*, especially regarding the increased flexibility of integrating obtained resources into existing local repositories of education material.

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II. On the Need for a Blockchain-Based Ecosystem to Manage Education Material

To motivate the need for a blockchain-based management system and market for digital education resources, we first discuss our assumed scenario and subsequently derive requirements and design goals for creating such a system that especially take security and practicality into account.

In a traditionally highly federated field, collaborations between universities are seldom. In this work, we seek to remedy this situation and note the following observations as a foundation for our proposed ecosystem. We envision a collaborative network consisting of *interconnected university institutes and third-party content providers* with a dedicated representative; the organization within a single institute is out of the scope of this work. Institutes are obligated to educate students and thus maintain a local *repository of educational resources*. Education resources may be diverse, i.e., they encompass lecture notes, slides, exercise and exam tasks.

We acknowledge that the creation of education material, i.e., a collection of education resources, may become burdensome without immediate payoff in perspective. Following the observed behaviors of users of peer-to-peer file sharing platforms [7], we thus assume an asymmetry regarding the demand and provision of educational material. While we anticipate few heavy *material providers*, most institutes are mere *users*, although any institute may assume both roles simultaneously with varying shifts towards either extreme. To avoid free-riding [8] of users, we must provide suitable incentives to actively contribute to the community.

However, material providers demand keeping control over their original education resources to be willing to share their material with other institutes which are potentially unknown to them. On the one hand, they must be able to decide whom to grant access to certain education resources to maintain confidentiality, e.g., considering highly specialized and research-oriented material. This condition implies that they must be able to maintain fine-granular access control. On the other hand, if an institute decides to conditionally share its education resources, the system must assure that users respect the terms of use, e.g., properly attribute the work's original source. Finally, providing financial compensation for an institute's efforts would further incentivize active contribution of new material or improvements.

Based on this scenario, we derive the following design goals for an ecosystem facilitating the collaborative management of education material across universities and their institutes.

(G1) Access Control and Accountability. Material providers must be able to decide whom to grant access to which of their education resources. Furthermore, they must be able to specify the fee for utilization, i.e, the price, and license terms associated with their work. Conversely, users must be able to browse accessible education resources to decide which material they want to request. All access-granting decisions must be recorded in a tamper-proof log to introduce accountability and liability for both material providers and users.

(G2) Collaborative and Transparent Improvements. The whole evolution of education material should be recorded in a transparent manner to enable participants to track changes and updates for specific education resources, effectively introducing a variant of version control. This requirement encompasses logging all traces of improvements to individual resources as well as recording comments and questions from users.

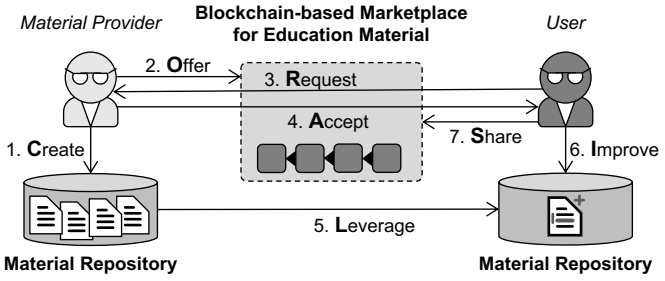


Fig. 1. Overview of our proposed blockchain-based platform for the collaborative maintenance of education material across university borders according to the CORALIS workflow: Material providers *create* and *offer* education resources for users to *request*. After the material provider *accepted* that request, the user may *leverage* it according to its terms of use. In a tit-for-tat manner, the user can subsequently *improve* the obtained material and *share* it again with the community.

(G3) Efficient and Sensible Storage Model. While material providers require that all developments are immutably recorded, we also acknowledge that education material must be revocable. Furthermore, the distributed nature of local repositories of each material provider must not hinder the accessibility of data (for external users and collaborators). This requirement is especially crucial when external users contribute to existing education material stored in a local repository under the control of a single material provider.

Next, we discuss our proposed approach for creating a blockchain-based platform to achieve these design goals and discuss challenges arising from our approach.

III. A Blockchain-based Marketplace for Education Material

In this section, we first provide an overview of our proposed blockchain-based platform for collaboratively managing education material. Subsequently, we discuss how our platform can achieve accountable access control. Besides, we highlight challenges for the distributed storage of education material considering a potentially large number of collaborators.

A. Design Overview

We base our blockchain-based platform, CORALIS, on a general workflow for the collaborative maintenance of education material. We illustrate the seven steps of this *CORALIS workflow* in Figure 1 and introduce them in the following.

Material providers first ***C**reate* a repository of education resources. Then, they can choose to ***O**ffer* selected material to other institutes, who then assume the role of users. All offered resources are announced on CORALIS' underlying permissioned blockchain, which is maintained collectively by material providers and users. Consequentially, each institute can create a local index of available education resources,

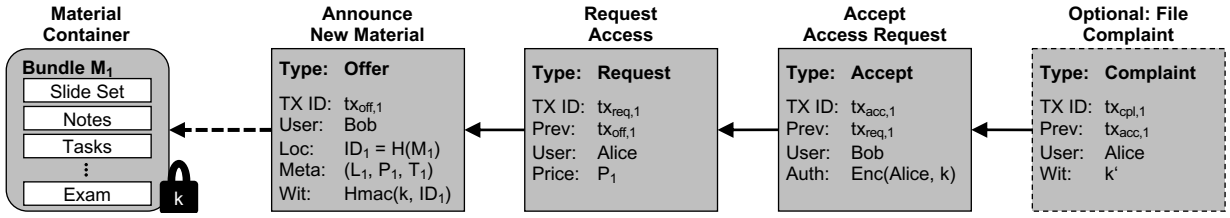


Fig. 2. We propose an on-chain three-way handshake for accountable access control that enforces education resources to be released only after the user irrevocably accepted the material provider's license terms and price asked. First, the provider offers new material in conjunction with relevant meta information. Then, users can request to access or purchase offered resources, thereby committing to abiding to their license terms. Finally, the provider accepts the request and simultaneously provides the user with the symmetric key required to access the purchased resources. If the user is cheated, e.g., she receives a wrong symmetric key, she can file an on-chain complaint to blame the misbehaving provider.

effectively establishing a marketplace for education material. To acquire desired material in an accountable manner, a user has to ***Request*** specific resources via an on-chain transaction, which the material provider has to explicitly ***Accept*** on-chain in return. After recording this mutual agreement on the blockchain, the user may obtain and ***Leverage*** the acquired material from the material provider. To contribute to the community in a tit-for-tat manner, the user can subsequently ***Improve*** the material and ***Share*** an updated version with the community. Improvements can either consist of changing education resources or discussing their content. Similar processes are well-established on platforms such as GitHub [9]. Furthermore, ratings reflect resources' perceived quality.

In the following, we first detail how CORALIS realizes accountable access control (Goal **G1**) and discuss challenges for keeping track of material improvements (Goal **G2**) as well as the distributed storage of education material (Goal **G3**).

B. Achieving Accountable Access Control

Figure 2 illustrates our approach of recording a three-way mutual agreement on the blockchain to address Goal **G1**, i.e., to achieve accountability and access control. Material providers keep all their education resources or compiled bundles thereof in individual, symmetrically encrypted *material containers*. This design ensures that the original provider remains in control over their resources even if the storage of material containers is outsourced to a third party as they can decide whom to disclose the symmetric key k to. To offer material to users, the provider publishes an *offer transaction* t_{off} to the blockchain, including an identifier of the material container, meta information that determines the *license terms* L in a concise form, the *price* P, and additional *index tags* T, and a witness of the container's validity.

The witness is needed if disputes between providers and users arise whether or not access has been granted correctly. It consists of an HMAC constructed over the container's identifier using the symmetric key k. By publishing a *request transaction* t_{req} referring to t_{off}, a user signals her interest in obtaining the material while simultaneously committing to paying the price P and abiding to the license terms L. The provider has to accept this request via an *accept transaction* t_{acc}, which provides the user with the key k required to access the material container's contents. CORALIS makes the whole mutual agreement process *publicly verifiable* to increase the detectability of misconduct.

However, the provider could try and provide the user with a wrong key k' to prevent her from accessing the material regardless of her payment. To avoid this pitfall, users can file an on-chain complaint against the provider's t_{acc}. By disclosing her received key k' in case of a dispute, the user can prove that the provider indeed shared k' in t_{acc} and she can prove that the validity witness of t_{off} does not match k'. Unfortunately, this approach cannot prevent the provider from constructing a meaningless material container in the first place. We thus propose to mitigate the impact of this inherent issue, which is known from content-offloading scenarios [10], by allowing users to post short and public on-chain ratings.

C. Transparently Storing Distributed Education Material

We now discuss challenges regarding storage requirements (Goal **G3**). We first discuss how to integrate the potentially large number of contributors for one material container into our system and then consider different storage models.

CORALIS must efficiently link multiple user contributions to the same education resource while respecting its confidentiality against users without access permission. In Figure 3, we detail how we integrate comments and improvements to education resources into our system. To keep education resources self-contained, we append comments addressing them to their respective material containers, encrypted via the same key k. However, comments are referenced on-chain as well to maintain transparency (Goal **G2**). We refrain from storing arbitrary user-generated data on-chain due to potential negative and hard-to-resolve side effects [11], [12]. With this approach, all relevant information for one material container

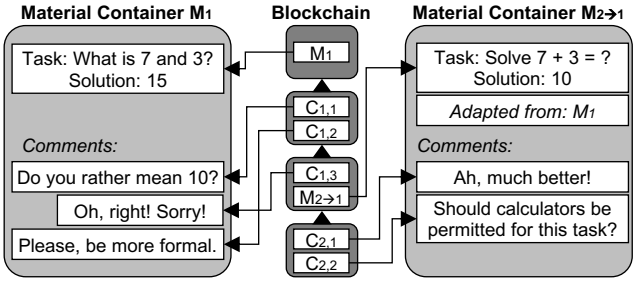
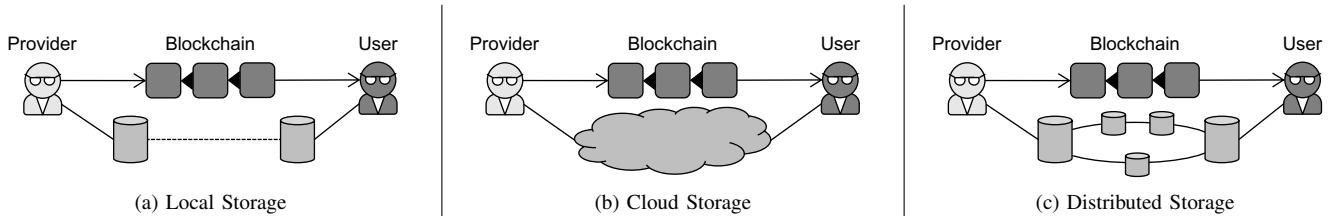


Fig. 3. The blockchain of our CORALIS platform constitutes an immutable ledger of the evolution of education resources that are stored off-chain.



(a) Local Storage (b) Cloud Storage (c) Distributed Storage

Fig. 4. Encrypted material containers enable providers take various approaches to persistently storing their material. CORALIS is compatible with (a) local per-provider repositories of education resources, (b) a centralized storage outsourced to, e.g., a public cloud, and (c) fully decentralized storage architectures.

can be obtained from a single source while the blockchain attests the container's integrity. Improvements, however, are stored in a new material container that only references the parent material container for transparency reasons. We chose this design to better suit the users' requirements of managing their (improved) education resources locally. Yet, as shown in Figure 4, our utilization of encrypted material containers also allows outsourcing their material containers securely to public clouds or a fully distributed storage to further address Goal **G3**.

IV. Immutable License Terms for Shareable Education Material

After describing our design for the CORALIS platform, we now focus on the aspect of how material providers and users can collaboratively utilize this ecosystem (Goals **G1** and **G2**). To this end, we first discuss how material providers can express license terms in Section IV-A. Subsequently, we elaborate on questions a license model must cover in our context in Section IV-B. Finally, we discuss the degrees of enforceability and challenges of disputes in Section IV-C.

A. Standards for Secure and Immutable License Agreements

As discussed in Section III-B, material providers must specify license terms when offering new material and users can only obtain material after immutably committing to abiding to these terms on CORALIS' blockchain. We now further discuss the requirements for expressing license terms in our context, outline an approach to implementing licensing terms in CORALIS based on these requirements, and identify aspects stemming from considerations regarding both usability and technical applicability.

Completeness. The specification of license terms must cover all relevant questions for any given type of education material to allow material providers to express their intended usage terms. This aspect is especially relevant for collaboratively created material.

Simple Formulation. CORALIS is intended to be a marketplace for quick and easy access to education material. To support this intention, license terms should be presented to interested users browsing available resources in a simple form to ease their comprehensibility. Consequently, all desired license terms should be easily expressible.

Concise Representation. As discussed in Section III-B, license terms must be strictly tied to a purchase and, therefore, they are included in the on-chain handshake between material providers and users. Hence, license terms ideally should allow for a concise on-chain representation.

Intuitively, these technical requirements contradict the usability considerations. When giving material providers more decision parameters when specifying license terms and requiring those terms to be expressed comprehensibly for users, these license terms inevitably gain a certain verbosity. This observation stands in contrast to our requirement for concise on-chain license terms. However, we can resolve this conflict by creating a *license chooser* for CORALIS as implemented for, e.g., End-User License Agreements (EULAs) [13] or resources for the public domain under the Creative Commons licenses [14]. A license chooser allows material providers to easily specify their license terms by answering a few questions and generating their final representation based on the submitted decisions. Hence, we only need to store the material provider's decisions on-chain to be parsed in a comprehensible form for interested users. To this end, the compact privacy policy language CPPL [15] promises to constitute a well-suited building block for CORALIS. CPPL was initially designed to enable owners of potentially sensitive data to attach compressed privacy policies to their data items before outsourcing them, e.g., storing them within a public cloud. The compression of CPPL is especially efficient due to its incorporation of domain-specific knowledge [15]. Thus, an adaption of CPPL's underlying compression scheme to express CORALIS' license terms is a very promising approach to fulfill the identified requirements of completeness, simplicity, and conciseness.

B. Considerations for a Comprehensive License Model

We now briefly present initial questions our license chooser needs to incorporate to provide a suitable licensing model. We identify the following fundamental specifications our license model must be able to express.

Target Audience. While we envision CORALIS to establish an open marketplace within the boundaries of the academic context, material providers still need to be able to exclude certain users from obtaining their resources. For instance, material providers may disallow any utilization that directly facilitates preparing students for research in military contexts.

Attribution. Material providers must be able to enforce proper attribution of their original works to establish a non-monetary incentive for creating material. Attribution terms can, e.g., require to name the original author, her affiliation, or funding sources in the context of an education resource. Furthermore, varying levels of required attribution can be

specified, such as a copyright notice on each lecture slide, or once on a dedicated slide, or no attribution at all.

Scope of Dissemination. A material provider must be able to restrict the dissemination of her work to prevent its uncontrolled multiplication. For instance, she can choose to allow certain fundamental exercise tasks to be freely distributed online, while advanced exercises must only be distributed in paper form among students attending a course.

Allowed Modifications. Finally, material providers can grant certain rights to modify purchased resources. Especially regarding the form of required attribution, unintended or poor modifications of education resources gain the potential to harm the original provider's reputation. Dealing with modifications of original work is a fundamental aspect for licensing of open source software [16], hence we envision that we can further seize experiences from that domain for our licensing model.

This initial framework serves as a foundation for future considerations as CORALIS' final licensing model will need to remain more tunable to address even complex situations.

C. Handling Licensing Disputes

After specifying the requirements for a licensing model, we now discuss to which extent CORALIS can help participants to resolve disputes over potential violations of license terms. Specifically, we argue that license terms cannot be technically enforced and that material providers and users have inherently conflicting interests. While material providers seek to protect their original work to the largest extent possible, users and their students can benefit from more relaxed terms of use.

Fundamentally, CORALIS cannot provide full enforceability of license terms since various forms of misconduct are hard to globally observe, monitor, or stem. For instance, users and students can collude to distribute education resources among each other that were only meant for presentation during a lecture. Similarly, students can make unauthorized copies of such resources. However, our platform transparently records each user's commitment to abide by the terms and therefore, potential violations can be investigated publicly against the license agreements. A related approach to public verifiability is already implemented, e.g., when publicly showing sports events without commercial subscriptions, where the broadcaster requires viewers to report any observed misconduct [17].

To support the identification of license violations, material providers need to enrich their resources with indicators reflecting permitted use. Referring to our previous example, permitted public transmissions of proprietary content can be indicated by small overlay icons [17]. A similar approach can be implemented to enable students to verify permitted use of shown resources, for instance by displaying QR codes in conjunction with the presented resource that link to the publicly verifiable mutual agreement within CORALIS' blockchain. Furthermore, material providers can make use of cryptographic means, such as Digital Rights Management (DRM) [18], to tie digital resources to their respective license terms.

This restrictive approach, however, stands in stark contrast to the interests of users and their students. Disallowing modifications to education resources and technically hindering such modifications can ultimately enable large material providers to essentially re-centralize the market for offered material [4]. Consequently, few global players would be enabled to effectively steer higher education. Actively *encouraging* certain levels of mutability, however, has the potential to greatly improve the experiences of both users and their students. For example, we consider education resources that are available in an appropriate standardized text format (e.g., LaTeX code) in small, self-contained chunks. This format enables users to seamlessly integrate these well-vetted education resources into their own material and thereby (a) successively and selectively increase their material's quality, (b) present material in a unified look and respect, e.g., corporate design requirements, and (c) tailor material to their students' needs. To illustrate the need for adapting education resources, consider the notation of complex numbers as a simple example. In mathematics, the imaginary unit is typically denoted by i, while j is used in electrical engineering to avoid confusion with currents. By enabling users to easily adjust such notation, they can effortlessly combine high-quality material from different sources. Hence, especially a simple adaptability of education resources promises great benefits for users and their students.

Even though CORALIS does not position itself explicitly within this trade-off between protecting original work and easing adaptability, disputes will likely arise over potential but not explicit violations of agreed-upon license terms. As already indicated, such disputes cannot be decided automatically in all cases, hence we need to address the question of how to deal with these situations on a completely decentralized platform. To this end, we propose to enhance the on-chain complaints of CORALIS (cf. Section III-B) such that material providers can also file complaints *after* a successful initial agreement to indicate alleged misconduct by users. However, our decentralized platform does not designate a dedicated party to resolve disputes based on these complaints. Instead of requiring *all* participants of CORALIS to redundantly investigate on-chain violation claims, we instead propose to adapt SmartJudge [6], a general-purpose framework for dispute resolution on public blockchains, for use in our ecosystem. Specifically, SmartJudge considers that interacting parties can mutually agree on a tie-breaking instance in case of a dispute. A slight adaption of this approach enables material providers and users to outsource the dispute resolution to a small mutually accepted jury of CORALIS participants to unburden the remaining participants.

In conclusion, CORALIS bears a high potential for exchanging education resources among mutually not fully trusting participants by providing an immutable and publicly verifiable distributed ledger of agreed-upon license terms. However, whether material providers decide to distribute their education resources in a more restrictive or adaptable manner currently remains an open question and will likely influence future business models involving CORALIS. Our platform addresses this issue through its general-purpose material containers (cf. Section III-B), hence material providers can distribute their material with varying degrees of technical protection.

V. Related Work

CORALIS is related to work considering blockchain data storage, distributed version control, and blockchain platforms facilitating social interaction or education processes.

Currently, education resources are shared either based on contractual agreements and commitments [2] or via isolated teaching repositories [3]. While definitively providing a step toward increased levels of collaboration, both approaches suffer from a rather narrow scope regarding the availability of vetted education resources. To maximize the benefit of high-quality education resources, inspired by the concept of data markets [19] and blockchain-like approaches to distributed configurability [20], we instead rely on a blockchain platform that is open to known material providers and users.

This choice raises questions regarding blockchain-backed storage models. We have previously shown that on-chain content storage can have devastating consequences for the whole ecosystem [11]. Hence, other approaches using a blockchain-based storage typically rely on tying their data to immutable on-chain evidence [21], [22], [23]. We share this general pattern with other blockchain-based platforms that realize, e.g., decentralized social networks [24] or a blockchain-based consistency check for mirrored software packages [25].

Combining and extending these promising applications, CORALIS facilitates the rating, discussion, and collaborative improvement of education resources. Related work also identified various benefits for blockchain platforms in education [26], for instance, for purposes of immutably recording student achievements [27], but also managing intellectual properties [26]. However, to the best of our knowledge, CORALIS is the first proposal to implement such a platform as of now regardless of its focus on the academic landscape.

VI. Conclusion and Future Work

In this paper, we motivated the need for a blockchain-based inter-university platform to facilitate the collaborative creation and improvement of high-quality education resources to effectively avoid redundant work. Our design focuses on material providers who should remain in control and on the establishment of accountable on-chain license agreements that are publicly verifiable via our CORALIS blockchain. We discussed the need for simple and concise license terms in our system and proposed to combine a simple-to-understand license chooser with a space-efficient policy language. Finally, we argued that technical means to report violations of license terms exist to resolve arising disputes within CORALIS.

Future work for CORALIS involves additional research into applicable business models, e.g., to properly reflect the trade-off between resource protection and flexibility in a resource's value or to further incentivize reviewing and improving existing education resources. Besides, we aim to evaluate the scalability limits of our proposed platform by deploying a proof-of-concept implementation. We plan to realize this implementation via established building blocks, such as Hyperledger Fabric for the blockchain backend of CORALIS, CPPL for our license agreements, and suitable data formats for expressing well-protected as well as highly adaptable education resources. Further, we see a potential for CORALIS to create an ecosystem among commercial software developers, i.e., to offer properly licensed, high-quality code fragments for recurring patterns.

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