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DEVELOPMENT ARTICLE

Constructing social media links to formal learning: A knowledge Graph Approach

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Abstract
While education increasingly relies on social media technologies to provide richer learning experiences, the rigid and course-centric design of curricula still imposes a challenge for students to construct meaningful connections between social media and formal learning. Building on the knowledge graphs' potential to establish semantic links among data entities, this paper investigates to what extent knowledge graph-based tools help students with integrating and accessing transdisciplinary social media content in formal courses, and contribute to constructivism in online learning environments? This study proposes a framework that includes a set of tools built on a novel knowledge graph designed to help educators in exposing detailed coverage of their formal courses through explicit concepts, which can serve as building blocks for students to integrate and access transdisciplinary social media content in formal learning settings. The framework is piloted in a business school where 180 students used these tools in an information systems (IS) course. The preliminary results indicate the majority (around 68%) of materials shared and accessed by students through this framework was connected to other disciplines beyond IS, reflecting the possible creation and exploration of transdisciplinary links between social media content and formal courses. Thirty-three students were interviewed to evaluate their opinion on the tools with respect to social constructivism in online learning environments. The interviews provide initial insights on the tools' potential to promote constructivism by supporting collaborative, learner-centered, high-quality, authentic, facilitated, and interactive learning principles. The study helps students and educators better integrate and access emerging social media content in formal courses.

Keywords Knowledge graphs · Semantic web · Social media · Social constructivism · Linked data · Ontologies

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Introduction

Currently, students and educators actively share, collaborate, and contribute knowledge through various social media and web-based platforms (Dabbagh & Kitsantas, 2012; Manca, 2020; Rüschoff & Ritter, 2001; Selwyn, 2012; Zarzour & Sellami, 2017). The learner's active engagement, coupled with the information surge using online platforms, can contribute to the idea that traditional curricula design in modular forms demarcated by clear disciplinary boundaries is "being replaced by human inquiry that draws upon generalized transdisciplinary bodies of knowledge and relationships" (Costa & Liebmann, 1995). While social media and web technologies can support students socially construct information (Huang, 2002; Manca, 2020; Zdravkova et al., 2012), it is still challenging for educators and students to integrate and connect transdisciplinary social media content with formal courses.

One of the factors that contribute to this challenge is the fact that most formal learning follow a rigid curriculum-driven design (Greenhow & Lewin, 2016), and rely on course syllabi, catalogs, and learning management systems (LMS) to represent and manage course information. This course-centric representation often lacks explicit transdisciplinary relations and creates information silos around "walled garden" courses (Mott, 2010). However, social media content typically cover concepts that are usually not explicitly defined at the course information level and are often transdisciplinary. Consider, for example, a student in a business school who discovers a new trending video on social media related to Bitcoin.[1] Connecting this video to formal business courses raises some questions that need to be answered, for example, does this video material belong to a technology course or a finance course? How can it be connected to both? To which part of each course is it relevant? How can it be explored in the context of several courses? In other words, the course-centric and rigid design of formal curricula hamper the construction of transdisciplinary relationships between emerging content on social media and formal courses. Subsequently, this difficulty can limit the possibilities of creating meaningful connections between new and existing knowledge resources (Anderson & Dron, 2011; Chen & Bryer, 2012; Hay, 2007; Novak, 2010), which can support constructivism in online learning environments (Huang, 2002). Furthermore, it may constrain students to perceive relations between concepts, ideas, and fields (Siemens, 2005), and inhibit them from building connections between real-world potential knowledge sources (e.g., social media) and classroom knowledge.

Research efforts investigate the potential of social media in linking informal to formal learning (e.g., Dabbagh & Kitsantas, 2012; Manca, 2020; Manca & Ranieri, 2016). These studies acknowledge the value that online social interactions bring to students' learning experience. Other studies recognize the benefits of organizing knowledge around concepts and semantic networks in learning contexts (Hay, 2007; Jonassen, 2006; Jonassen & Marra, 1994; Novak, 2010). In parallel, emerging web technologies and knowledge graphs (Fensel et al., 2020; Hogan et al., 2021) increasingly support the construction and representation of educational knowledge with conceptual links at the data level (Nahhas et al., 2018; Pereira et al., 2018). However, studies on the construction of explicit linkages between social media and formal curriculum contents remain scarce. This work contributes to this stream of efforts, with the aim of addressing the following research question: *to what extent do knowledge graph-based tools help students with integrating and accessing transdisci-*

[1] At the time of writing this paper, cryptocurrencies (e.g., Bitcoin) were trending digital assets that were challenging conventional mediums of exchange, providing new investment and service opportunities.

plinary social media contents in formal courses, and contribute to constructivism in online learning environments?

Background and Literature Review

Similar to other fields, education is undergoing transformational changes induced by current web and social media technologies (Manca, 2020; Zachos et al., 2018; Zdravkova et al., 2012). Online platforms provide new means for students and teachers to interact, collaborate, and experience learning materials that extend their formal learning setting. Manca's (2020) review of using social media in higher education reveals the extent to which different social media platforms afford mixing learning resources and information, involving external expertise from social networks, and integrating personal, social, and learning contexts. While the reviewed platforms (i.e., Whatsapp, Instagram, Snapshat, and Pinterest) contributed to offering interactive features differently, the adoption of social and web technologies in learning practices will continue to evolve. This paper reviews efforts to investigate the role of social media in learning environments, and the role of concepts and emerging web technologies in constructing and representing educational knowledge.

Role of Social Media in Learning Environments

There is an increased interest in studying the role of social media in connecting formal and informal learning (Bull et al., 2008; Chen & Bryer, 2012; Dabbagh & Kitsantas, 2012; Greenhow & Lewin, 2016; Jong et al., 2014; Lockyer & Patterson, 2008; Manca, 2020; Manca & Ranieri, 2016). Bull et al. (2008) pointed out the advantages of observing how students share and manipulate content on social media. They articulated the challenges that educators face when integrating interesting online materials on formal content related to their curriculum. Such a challenge intensifies when formal learning materials are delivered and discussed in an isolated course-based setup, which is the case for most traditional higher education systems. On a related note, Lockyer and Patterson (2008) assessed the social media impact on formal learning processes. They provided evidence that social media can have positive learning outcomes in formal education environments. One of their observations reveals that a potential limitation inhibiting the adoption of social media technologies is the blurred line between personal and academic contexts. Students and lecturers may avoid using social media platforms as they find themselves exposing their private information in professional contexts. Greenhow and Lewin (2016) proposed a model that dissects the attributes of formal, informal, and social media. Their case studies shed light on how the use of social media is blurring the boundary between formal and informal education. Dabbagh and Kitsantas (2012) reflect how social media acts as a bridge between informal and formal learning, enabling seamless integration between the two. They proposed a framework to guide students while using social media to provide them with a self-regulated and self-centered learning experience. In this framework, different social media tools were aggregated and analyzed in regard to their capacities to support self-learning practices. The tools included wikis, media-sharing platforms (e.g., YouTube), social networking sites (e.g., Facebook and LinkedIn), and social bookmarking. Furthermore, Greenhow and Lewin

(2016) highlighted how the involvement of students in sharing content on social media led to unprecedented and unplanned outcomes for teachers.

The ease of creating, sharing, and interacting with content on social networks is becoming the new norm in communication. To follow up on this trend, universities and educators invest time and effort in employing social media in their teaching and learning activities. The presence of web-mediated platforms is shifting the responsibility of educators from purely designing, defining, and assigning content to helping students make connections between new and existing knowledge resources (Anderson & Dron, 2011; Chen & Bryer, 2012). However, some believe that such attempts are often perceived as artificial attempts to bridge this gap, creating a digital disconnect between universities and students (Selwyn, 2012). Some of the reasons behind this disconnect include the lack of institutional support of social media platforms—similar to their backing of official LMSs, which they can tightly control—and the development of home-grown social online platforms, which have a low chance of success when meeting students' expectations that match the offerings of popular social platforms, such as LinkedIn or Facebook (Anderson & Dron, 2017). While existing research efforts study the impact and role of social media on formal learning settings, they fall short of investigating how to explicitly and conceptually connect social media content with formal courses. A core objective of this work is to study the feasibility of bridging widely-used social media features to LMS platforms, while offering the possibility of sharing and managing learning resources in a transdisciplinary manner that is deemed challenging in course-centric LMS design.

Role of Concepts and Emerging Web Technologies in Learning Environments

"Concepts and categories serve as building blocks for human thought and behavior" (Medin, 1989). The development of concept maps and connections between new and existing knowledge structures reflects new learning opportunities for students (Hay, 2007; Jonassen & Marra, 1994; Novak, 2010). Such conceptual connections allow learners to easily explore and tap into new fields of knowledge (Siemens, 2005). Concepts and concept maps play a major role in designing more effective instructions and student assessments (Jonassen, 2006). However, constructing concepts to bridge informal social media sources to formal learning remains underexplored and presents additional challenges. This includes, for example, the difficulty in tracing the source of concepts to their related formal courses and informal online sources, using such concepts to integrate social media resources into existing learning management systems or other platforms, and capturing related social information (e.g., exchanged comments on shared material).

The web has progressed to become "a common tool for learner-centered or constructivist learning" (Huang, 2002). It enables the creation of a continuously evolving network of nodes connecting content, people, and organizations in unprecedented ways. Today the web increasingly includes explicit semantic connections at the data level through knowledge graphs and semantic web ontologies in various domains (Berners-Lee et al., 2001; Fensel et al., 2020; Hogan et al., 2021), including education (Nahhas et al., 2018; Pereira et al., 2018). Knowledge graphs are defined as a "graph of data intended to accumulate and convey knowledge of the real world, whose nodes represent entities of interest and whose edges represent relations between these entities" (Hogan et al., 2021). Computational ontologies

serve as a means to provide a concise definition of such nodes and their relations for a consistent data representation and exchange across distributed systems (Guarino et al., 2009).

In the education context, Muñoz et al. (2015) proposed an OntoSakai ontology to represent the user context for improving the process of recommending resources through a set of explicitly defined expert rules. Furthermore, Kurilovas et al. (2014) designed an ontology to embody learning objects that can be manipulated, based on specific learning objectives and activities. Similarly, ontologies have been used to model feedback to render e-learning systems more personal (Cheniti Belcadhi, 2016) and adaptive to students' contexts (Rani et al., 2015; Yaghmaie & Bahreininejad, 2011). Zhuhadar et al. (2015) proposed a platform to semantically connect and enrich massive open online courses (MOOC) and focused on the collaborative semantic filtering aspect of learning objects. Subject ontologies have also been adopted to manage relationships across curriculum topics, aiming to assess the efficiency of answering queries related to topical coverage in courses (Miranda et al., 2016). We observe the capabilities of ontologies and knowledge graphs in turning implicit and hidden connections into explicit and semantically rich data that can be used to create smarter and more sophisticated applications on the web in general, and online learning environments in specific.

Ontologies have been proposed to support collaborative learning by capturing course content through a set of rules (Alomari et al., 2015; Fernández-Breis et al., 2012). These rules are transformed into an ontology for a shared representation among professors and learners. Similarly, Zarzour and Sellami (2017) proposed the use of semantic web technologies to support collaborative learning and resource annotation. Furthermore, the Courseware (Courseware RKB Explorer, 2012), TEACH (Kauppinen et al., 2012), and Academic Institution Internal Structure Ontology (Styles & Shabir, 2008) were proposed to represent curriculum and organizational structure information. Some approaches have gone beyond the representation and identification of learning objects to additionally represent the learning process through ontologies that capture the learning activities performed along learning paths (Gladun et al., 2009; Ouf et al., 2017). Those research efforts serve as evidence of the potentials of ontologies in representing not only learning resources, but also in supporting learning processes and boosting the social aspect of learning through improved collaborative learning.

Parallel to the above efforts, knowledge graphs and linked data are used to maximize web-scale visibility and interconnectedness of learning entities (d'Aquin, 2016; Dietze et al., 2013; Pereira et al., 2018; Zablith et al., 2015). The simplicity of linked data principles, when carefully followed, has proven to be effective in evolving an interconnected global data graph with explicit semantics (Heath & Bizer, 2011). Heath et al. (2012) proposed an education graph to connect learning resources adopted by several universities. Their objective was to process learning resources, identify shared concepts, and create a graph that connects resources used by several United Kingdom-based universities. We observe that most of the existing knowledge graphs and ontologies in the educational domain focus either on representing formal curriculum information to support internal learning processes, or in connecting online resources generated by educational organizations to improve their external data exchange. We see an opportunity for building on the knowledge graphs' capabilities for a seamless data exchange between socially exchanged learning objects that can be integrated in formal learning management systems.

This review reveals that while there is increased interest in investigating the adoption of social media for linking informal to formal learning settings, the existing studies fall short in providing the means to construct explicit conceptual links between social media and formal courses. This work aims to fill this gap by proposing a knowledge graph-based framework to integrate social media sources with formal curriculum content.

Methods

Integrating Social Media in Learning Environments: Trends and Challenges

One of the observed trends in higher education is when it comes to experiential study and venturing into new emerging topics, professors and students increasingly rely on social media to find relevant materials. However, existing research identified some challenges that are impacting the wider adoption of social media in education. Social media and e-learning management platforms have proven beneficial, depending on the task at hand. For example, Facebook was more convenient when sharing educational resources, however, e-learning platforms were better for reviewing resources organized around certain course topics (Jong et al., 2014). Besides, developing homegrown social platforms that provide custom-made features was not effective in meeting students' expectations offered by popular social media platforms (Anderson & Dron, 2017). Another particular aspect is related to catering for the informal setting of a "self-determined community of interest" (Greenhow & Lewin, 2016) that cuts across disciplinary boundaries (Costa & Liebmann, 1995) while maintaining connections to formal curriculum standards controlled by educational institutions.

The aforementioned challenges required additional concrete insights on students' engagement with online educational resources on social platforms. Such insights would serve as further guidelines for designing specific features to support students with socially constructing transdisciplinary connections between learning resources and formal courses. As part of a business school initiative to create richer learning experiences for its students, this study further examined how students engage in sharing and accessing information from social media that are pertinent to their learning context in one of the school's courses. The following shortcomings were identified: First, it is challenging for students to relate the materials they are sharing in a flexible way across courses in their degree. For students, the course material for the Bitcoin video example presented earlier is neither IS nor finance-related, it is both (i.e., transdisciplinary). This aligns with the community-driven interests that challenge the formal curriculum design (Greenhow & Lewin, 2016). Hence, exposing formal course content coverage with more details (i.e., at the concept level) may assist students in relating their shared materials with courses more flexibly. Second, it is challenging for students to discover such socially shared transdisciplinary material in their existing learning platforms. Currently, on existing learning platforms, most course pages are designed in isolation, making it hard to seamlessly discover the same material (e.g., Bitcoin) in the context of different courses (e.g., IS and Finance). This reflects the advantages of learning management systems in organizing knowledge around topical coverage compared to free-flowing content exchanged on social media platforms (Jong et al., 2014). Similar to the exploratory features of today's search engines, students may benefit from having course

pages with dynamic content that automatically updates materials conceptually relevant to the course's topics in focus.

Proposed Framework for Bridging Social Media Information to Formal Courses

Based on the challenges identified from the literature and from observing students' engagement with sharing and accessing online learning resources, this study builds on the evolution of the web (Berners-Lee et al., 2001; Zdravkova et al., 2012) and knowledge graphs (Fensel et al., 2020; Hogan et al., 2021) to design tools aiming to meet our research objectives. Two perspectives should be considered: first, theoretically, what concept structure could benefit both the formal course knowledge building and the transdisciplinary knowledge building; second, technically, what technology can support the realization of this content structure and its construction. Drawing on knowledge graphs to "integrate various and heterogeneous information sources to represent knowledge about certain domains of discourse" (Fensel et al., 2020), and the advantages of conceptually representing exchanged knowledge in the learning process (Hay, 2007; Jonassen, 2006; Novak, 2010), we propose a framework to bridge social media and formal courses content through a set of modules depicted in Fig. 1.

The framework addresses the identified challenges as follows. It includes a *Socio-Education* knowledge graph following a novel ontology that represents the conceptual structure needed to integrate information derived from students sharing social media content with explicit conceptual connections to formal courses. The knowledge graph aims to create explicit data relationships between content generated from "community-driven interests" (Greenhow & Lewin, 2016) and formal learning contexts. In addition, the framework enables educators to represent and expose their formal courses' resources in more detail—at the concept level—in the knowledge graph through a *Course Entities Creator* tool, which serves as a guide for curriculum designers to map their formal courses following the ontological relations defined for the knowledge graph. This attempts to expose the curriculum data beyond the "walled garden" setup of LMS (Mott, 2010). Furthermore, the framework offers three innovative tools to aid students in integrating and accessing social media in formal courses as follows: first, building on the advantages of conceptually representing learning resources (Hay, 2007; Jonassen, 2006; Novak, 2010), a *Social Bookmarker* was designed to allow students to link social media resources to formal courses with a high degree of flexibility through the formal concepts defined in the knowledge graph, or to introduce new ones. Second, to bring the best of social media's capabilities to seamlessly share and comment on content, as well as LMS's capability to manage knowledge around curricula's topical coverage (Jong et al., 2014), the *Social-LMS Explorer* tool was designed to

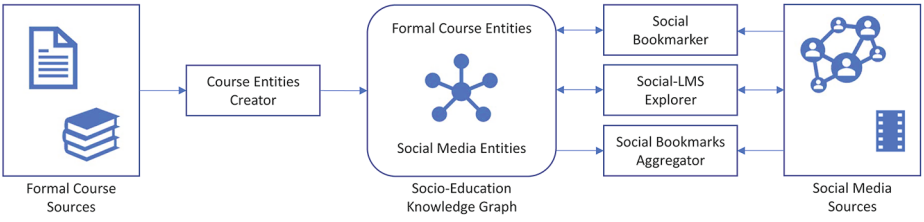

Fig. 1 Framework's modules overview for connecting formal courses with social media

enable students to access bookmarked social media content from within their existing LMS by exploiting the conceptual links defined in the graph. Third, the knowledge graph data was further exploited to develop a "timeline"-based (Jong et al., 2014) view of materials (i.e., organized with respect to when content was shared rather than around course topical coverage) through a *Social Bookmarks Aggregator* tool, aiding students to track and explore the shared social media resources and related comments on a centralized webpage.

Ontology for Establishing the Socio-Education Knowledge Graph

The proposed Socio-Education knowledge graph transforms the representation of walled garden formal curriculum courses and social media resources into flexible knowledge structures of linked entities. Figure 2 depicts the proposed ontology to represent the formal courses and social media entities on the knowledge graph.

Formal Course Entities Formal course entities (upper part, Fig. 2) represent the existing courses' information offered by educators in formal curricula. This part of the ontology aims to assist educators in exposing their courses' information in more detail in a structured and more accessible way. One of the key requirements for improving the representation, connection, and exchange of data through knowledge graphs is the reuse of available ontologies. Hence, we reuse and extend the provided representations of formal course entities in several existing ontologies presented in the previous section, namely, Courseware, AIISO, and TEACH. In the graph, courses have a *course number*, *credit hours*, *learning goals*, *specific learning objectives*, *description*, and *topics*. Courses are also connected to the *subjects* that they are part of, to the *organizations* at which they are taught, to the *assessment methods* used, and to the *instructional methodologies* adopted in them. One key design feature of the Socio-Education graph is that it captures the learning *concepts* covered in each topic of a formal course, for establishing linkages with social media materials.

Social Media Entities The ontology extends the connections between formal course entities and social media materials shared by students (lower part, Fig. 2). The material properties include a *URL*, a *description*, and a *type* to differentiate between, for example, books, videos, and articles. Like courses, the ontology represents the *concepts* covered in the materials. Rather than specifying a social media material is relevant to a course, students are required to specify how it is relevant by explicitly defining the covered concepts. In other words, a material is linked to the course only if they share common learning concepts. This concept-driven linking approach, which allows linking one material to many courses, is a core enabler for the construction of explicit transdisciplinary relations between social media materials and formal courses. Social interactions are captured by connecting shared material to existing social media graphs, for example, Facebook graph (Ugander et al., 2011) and Twitter ("Twitter Developer Platform," n.d.) Application Programming Interfaces (APIs) that enable access to their graph data at the application level. A *person* is represented in the Socio-Education graph as an entity who can *share*, *like*, *ask for help*, and *comment* on materials. The *first* and *last names* of the person are modeled along with their *online account* details, *mailbox*, and *title*. The person entity is based on the Friend-of-a-Friend (FOAF) ontology (Brickley & Miller, 2010), which aims to model the social connections among

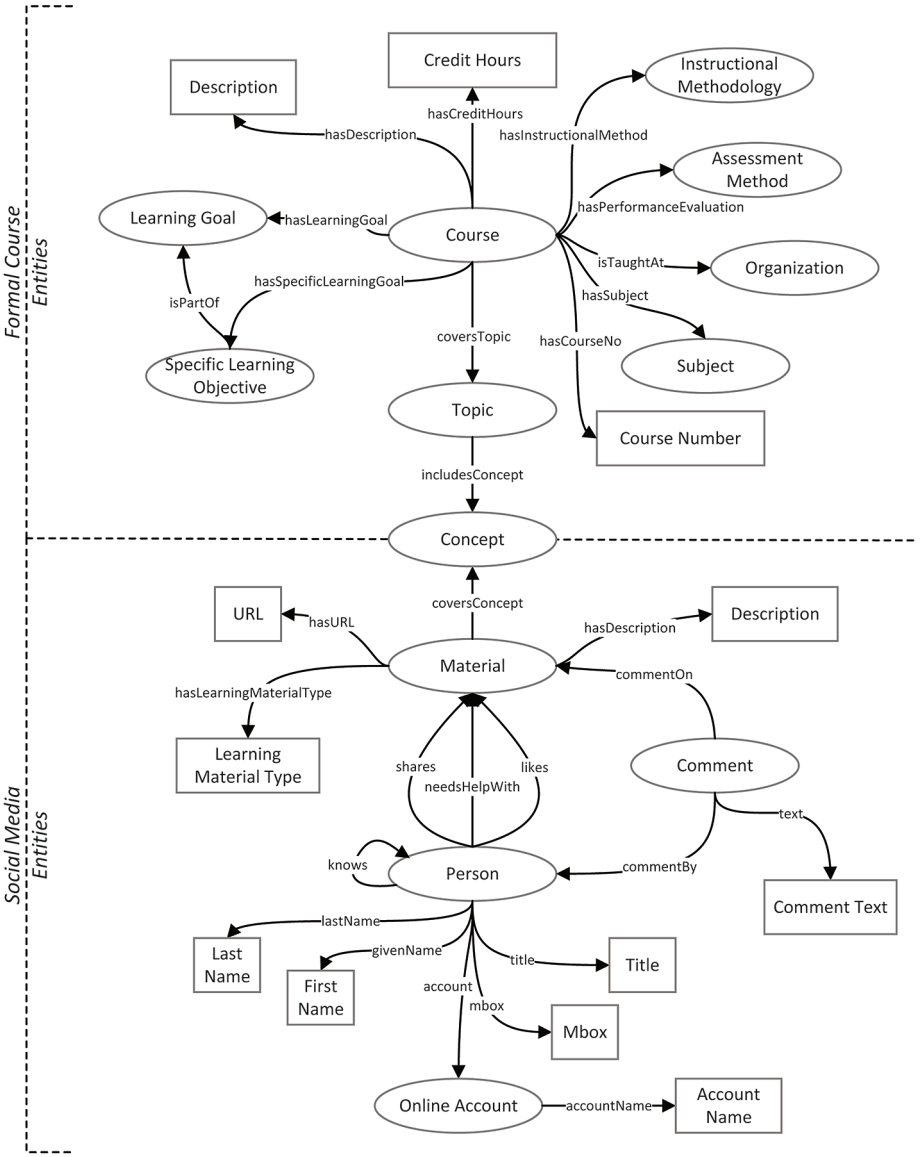

Fig. 2 Ontology for establishing the socio-education knowledge graph

people with explicit semantics on the web. The knowledge graph ontology schema can be accessed online.[2]

[2] The ontology schema source is available at https://linked.aub.edu.lb/ontologies/socioeducation.

Developed Tools for Integrating and Accessing Social Media and Formal Course Entities

Course Entities Creator The Course Entities Creator tool was prototyped using a semantic MediaWiki (Krötzsch et al., 2006). This module aids educators in collaboratively transforming their formal course information, topics, and concepts into entities on the proposed Socio-Education knowledge graph. The wiki was set up based on the formal course entities defined in the ontology. Students integrated and accessed social media entities within formal courses using three novel tools that are described next.

Social Bookmarker The Social Bookmarker tool (Fig. 3) features *bookmarking social media materials to formal courses* through new concepts and existing ones defined in the knowledge graph. The tool was developed using a JavaScript-based bookmarklet that resides within an internet browser. When students identify relevant online materials (e.g., the Bitcoin YouTube material shown in part 1, Fig. 3), they click on the bookmarklet (part 2, Fig. 3), which automatically extracts the material title and description from the associated webpage (parts 3 and 4, Fig. 3). Subsequently, students need to specify the concepts covered in the material. As per the proposed knowledge graph, concepts serve as building blocks to connect social media materials with formal courses. When students start typing the concepts in the interface (part 5, Fig. 3) a concept-matching feature is triggered to automatically match the concepts typed to existing concepts in the Socio-Education knowledge graph—without revealing to students which courses the concepts are connected to. Part 5, Fig. 3 shows the list of matching concepts in the knowledge graph when typing *invest* in the text box. Transdisciplinary links are formed with the material that covers concepts that belong to more than one course. For example (part 5, Fig. 3), the concepts specified include *information technology* linked through the knowledge graph to an IS course (part 6, Fig. 3), and *investing activities* linked to a finance course (part 7, Fig. 3), hence creating a transdisciplinary relation between the Bitcoin material and the IS and Finance courses. Moreover, students may specify new concepts (e.g., Fintech and Bitcoin shown in part 5, Fig. 3) and are captured as a means to fill potential gaps in the curriculum.

Social-LMS Explorer The Social-LMS Explorer enables students to access and *explore social media content within an LMS* (e.g., Moodle). This tool automatically traverses the Socio-Education graph links to discover social media materials conceptually connected to

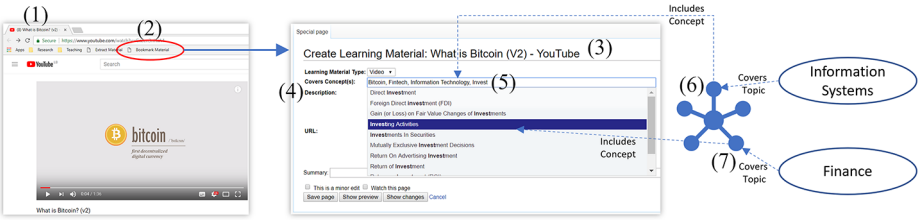

Fig. 3 Social bookmarker tool showing a scenario of connecting a bitcoin youtube material to IS and finance

formal courses. Figure 4 shows a scenario of a student exploring a material related to an IS course on Moodle. This feature was developed through a bookmarklet button (part 1, Fig. 4) that, when pressed, performs several functions. It detects the course in context, scans the course topics on the Moodle page, and automatically identifies the concepts linked to topics from the Socio-Education graph. Moreover, it gets the list of materials related to identified concepts and renders on the Moodle page clickable buttons, which dynamically appear next to the related topic (part 2, Fig. 4). This is performed without modifying the source code of the Moodle pages. When a student clicks on a button, the list of bookmarked materials related to the topic will be displayed in a pop-up window (e.g., part 3, Fig. 4 showing related material to the *organizations and information systems* topic). A student is then able to access the material in another pop-up window (e.g., part 4, Fig. 4 shows material related to Enterprise Resource Planning [ERP], a core concept of the information systems course, in which students discuss the potential of consolidating enterprises' departmental data in a centralized manner).

Another feature that was enabled through concept-driven links is the possibility for *transdisciplinary material to appear in more than one course*. The knowledge graph link-

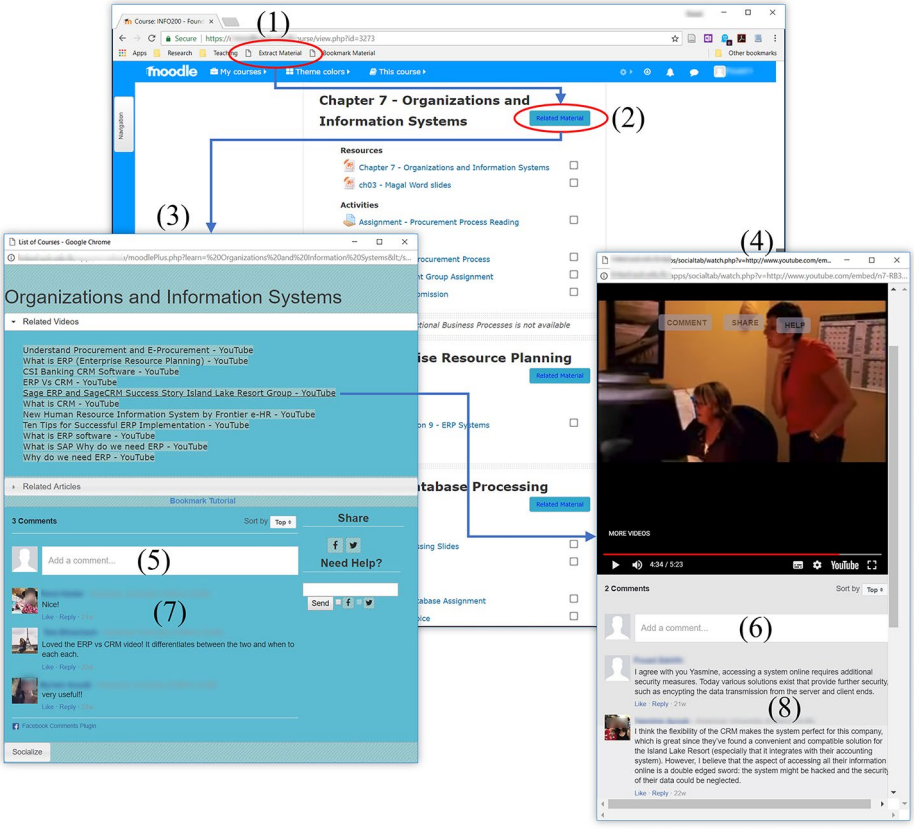

Fig. 4 Screenshots of the social-LMS explorer

ages supported this feature by relating formal courses to transdisciplinary social media content. For example, if the same ERP material that appears on the IS course page (Fig. 4) was bookmarked by students with the *organization efficiency* concept, which is also covered in the management course, the graph linkages will make this material automatically appear on the Moodle page of the management course. This feature reflects the ability to break through the isolated course pages designed on the LMS by enabling students to explore the same material in the context of different courses.

Furthermore, another feature was developed to enable students to *comment on materials* using their social media account from within the tool, which links the comments to material and sharer information in the knowledge graph. A social connector to the Facebook Graph API (Ugander et al., 2011) was set up so that students can log in to their Facebook accounts from within Moodle. Once users sign in to Facebook, they can give their consent to capture and connect their social information to the Socio-Education graph, including their first and last names, social account ID, and shared email. A social graph listener was implemented and triggered whenever a student comments on the topic or material (e.g., parts 5 and 6, Fig. 4). The listener captures all comment details on specific materials and topics in the curriculum and links them to the Socio-Education graph. When a topic or material is explored from within Moodle, the related comments are automatically extracted from the Facebook graph and displayed under that topic or material (e.g., parts 7 and 8, Fig. 4).

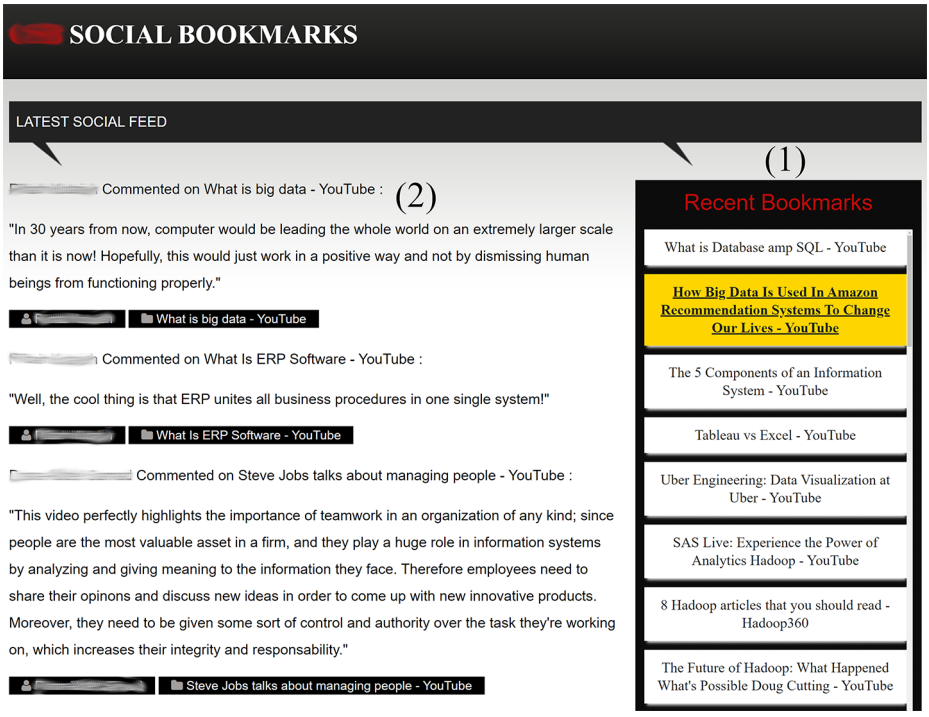

Fig. 5 Social bookmarks aggregator

Social Bookmarks Aggregator The Social Bookmarks Aggregator tool was developed to give students the ability to track and view recently bookmarked materials (part 1, Fig. 5), with the latest comments rendered in chronological order (part 2, Fig. 5) on one page. The *aggregate social bookmarking browser* functionality is implemented by accessing the Socio-Education graph data and rendering the results on an external webpage.[3]

Evaluating and Piloting the Framework in a Business School Program

The proposed framework was evaluated at two levels. First, we evaluate the extent to which the tools helped students conceptually link transdisciplinary social media materials and formal courses by inspecting the student-created concepts and links through the Socio-Education knowledge graph. Second, we perform an initial descriptive analysis of the tools' potential with supporting social constructivism through a set of semi-structured interviews, evaluated to uncover students' opinions on the tools' features in this context.

The proposed framework was piloted in the context of a business school (hosting approximately 1,200 students) of a university (hosting over 9,000 students). The evaluation was performed in the undergraduate IS core course of the school's curriculum. Limiting the setup to one course enabled assessing students' potential ability to create and access transdisciplinary relations between social media materials and courses beyond the IS discipline.

To create the formal course entities in the knowledge graph, we processed, with the help of course instructors and teaching assistants, the undergraduate courses' coverage of the different subjects in the business degree curriculum. The high-level course information was identified mainly from course syllabi, such as topics covered per course, subjects (e.g., finance, marketing, IS, and others), number of credits, course prerequisites, and learning objectives. We relied on existing textbooks to identify the detailed formal concepts covered. The identified course entities were collaboratively captured using the semantic MediaWiki platform,[4] part of a larger project initiative to represent university data on the web. More than 2,500 formal concepts were initially identified, with explicit connections to 18 business courses.

Participants

The three tools developed were made accessible to students enrolled in the undergraduate IS course. In total, approximately 180 students were involved in collecting, bookmarking, or interacting with social media content in the context of the course. Students were also invited to perform evaluation tasks where they were given new material to bookmark, complemented by semi-structured interview-style feedback. Thirty-three students volunteered, with no additional incentive, to be part of the follow-up interviews. In the sample, 54% of students were female, and 46% were male. Regarding the students' enrolled majors, the sample was representative of the school's student body. Most of the students in the sample (82%) were in year two, as students usually enroll in the IS course during their second year. 9% of the students in the sample were in their first year, and the remaining students were in

[3] The tool is accessible at https://linked.aub.edu.lb/apps/socialbookmarks/.

[4] Courses available are accessible at https://linked.aub.edu.lb/collab/index.php/Category:Courses.

their third year—the final year of the three-year business administration program. 21% of the students in the sample were pursuing an additional major or minor outside the school of business.

Data Collection

The 180 students were encouraged, as an extra activity throughout the IS course, to bookmark and interact with new social media resources that were relevant to course topics. The students were instructed to specify concepts covered by the material they were sharing. Over this period, 95 of the involved students bookmarked a total of 133 IS-related materials, while the remaining limited their involvement to accessing and commenting on materials. Of the students who bookmarked, 88% contributed one material, 8% shared two materials, and 4% shared more than two materials. Twenty-seven comments were exchanged using the tools. Following a well-defined protocol, semi-structured interviews were conducted individually to ensure consistency across the sessions (protocol detailed in the Appendix). The tasks and questions focused on various aspects of the tools proposed, and on the notion of being socially involved in contributing additional material to the curriculum content. With Institutional Review Board approval and student consent, the interviews were audio-recorded, and the computer screens were captured during student interactions with the tools. The sessions were designed to last approximately 20 min. A total of approximately 11.1 h of video were recorded.

Data Processing Methodology

Detecting Transdisciplinary Links between Social Media Content and Formal Courses

To detect the transdisciplinary connections between formal courses and social media, the nodes and links in the Socio-Education knowledge graph were processed as follows: we first queried the knowledge graph for the concepts used by students when bookmarking social media material. Then we identified from those concepts the ones linked to formal courses. Finally, we selected the bookmarked materials that linked to courses beyond the IS discipline.

Processing Student Interviews

To explore tool potential in supporting social constructivism, the recorded interviews of the 33 volunteer students were transcribed into text and then processed in three phases. In the first phase, the segments of text referring to tool features and overall tool support were identified and extracted from the dataset. The tool features were numbered as follows: [1] references *bookmarking social media materials to formal courses*; [2] references *material exploration within Moodle*; [3] references *commenting on material*; [4] references *aggregate social bookmarking page*; [5] references *same material appearing in more than one course on Moodle*; and [6] references *overall tool help with studies*.

In the second phase, six learning principles promoting constructivism in online environments were used to code text segments. The principles include: *Interactive learning* to stimulate and motivate students to reflect on the learning process and actively engage

with the content; *Collaborative learning* to foster cooperation among peers while achieving set learning goals; *Facilitating learning* to improve access to knowledge for students and instructors; *Authentic learning* to provide students with the ability to construct authentic and meaningful knowledge that goes beyond the boundaries of learning environments; *Learner-centered learning* to provide students with ways to selectively identify resources that can be adapted to their personal needs and learning goals; and *High-quality learning* to support students with the right level of control to synthesize, discuss, assess, connect, and manage information to construct meaningful knowledge (Huang, 2002). Processing the interview text data resulted in a total of 286 text segments referencing the six learning principles.

In the third phase, the students' answers were processed to check their opinions of the tool features with respect to the learning principles. Text segments were coded to identify (1) a positive sentiment when a participant explicitly showed constructive support of the feature in focus; (2) a negative one when the participant showed dissatisfaction with or concern about the discussed feature; and (3) a neutral sentiment, when the participant expressed no clear sentiment. The coding was performed using Nvivo (Bazeley & Jackson, 2013), and two analysts processed the data independently to infer the agreement levels. Cohen's kappa interrater agreement of the coded learning principles was 61.67% for the learning principle coding and 81.94% for the sentiment coding. These agreement rates are considered good to very good (Salkind, 2010; Landis & Koch, 1977).

Results

Student-created Transdisciplinary Relations

Initial results indicate students used the tools to relate 133 social media materials to a total of 230 concepts, among which 179 concepts connected through the knowledge graph to 11 formal business courses, and 51 were new to the course coverage at the business school. Figure 6 depicts the results of the transdisciplinary relations. The chart renders 11 formal courses in a circular layout, connected through links with widths representing the relative number of social media materials shared between the courses. As one would expect, given that the task was performed within the IS course, most of the social media materials are related to information systems (the right-hand part, Fig. 6). Furthermore, part of the materials (around 32%) include concepts that are not covered beyond the IS discipline (part 1, Fig. 6). However, most of the materials (around 68%) connect to concepts outside the scope of IS. A subset of those materials exclusively integrated new domain concepts with no relation to other courses (part 2, Fig. 6). Such new concepts can serve as a goldmine for educators, who can discover trending topics on social networks from students, and evaluate whether to introduce them to the curriculum. More importantly, students' activities resulted with materials linking the IS course to the following courses, listed in decreasing order of the number of shared materials: accounting, marketing, operations management, management, business ethics, managerial economics, and strategic management. Such links provide preliminary evidence of the ability of the knowledge graph-based tools to break through course boundaries and create transdisciplinary relations between formal courses and social media content.

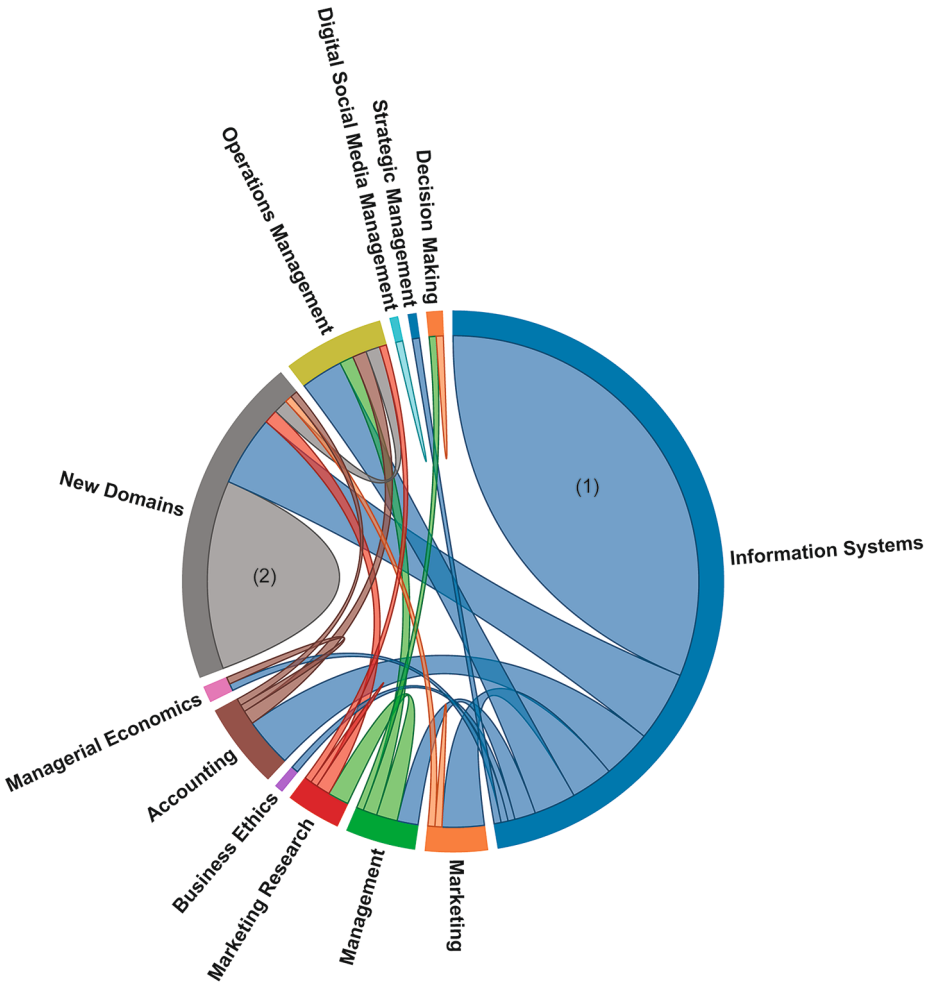

Fig. 6 Transdisciplinary relations among formal courses resulting from social media material shared by students

Reflections on Students' Interviews vis-à-vis Constructivism

The preliminary data analysis reveals six learning principles that promote constructivism (Huang, 2002) were referenced in student interviews at varying levels. The majority of the coded interview text segments referenced *facilitating learning*, followed by references to *high-quality learning*, then *interactive learning*, *collaborative learning*, *authentic learning*, and lastly by *learner-centered learning*. To get further insights based on student opinions on the tool features, the overall students' sentiment index is computed for each feature 1-6 based on the difference between the positive and negative percentages detected from the interview text segments. The index is used to sort and rank the tool features favored by students, as reported in Fig. 7. Each feature is described next with a sample of related state-

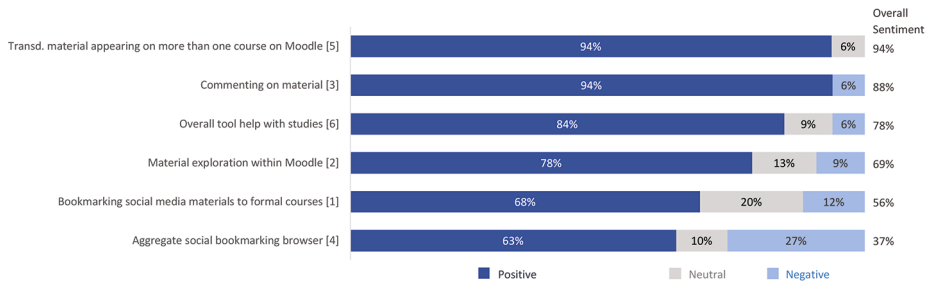

Fig. 7 Students' sentiments about the proposed tools' features

ments verbalized by students during the interviews, with reflections on the related learning principles.

Transdisciplinary Material Appearing in More than One Course on Moodle Interestingly, the feature that received the highest overall sentiment was the new possibilities of transdisciplinary social media materials appearing in more than one course on Moodle, with 94% positive and 6% neutral sentiments. This feature triggered references to all the learning principles, except the *interactive learning* principle. For example, one student mentioned the following:

> *The first thing I had in mind when you mentioned this feature is silos; it minimizes them between courses, so it relates the courses together and helps you understand the big picture*.

This statement highlights that knowledge graph connections made it possible to relate courses and break their isolation through transdisciplinary social media material. This helped students understand the big picture of the university degree, subsequently supporting the *high-quality learning* principle.

Commenting on Material The feature of commenting on material from within Moodle received 94% positive and a 6% negative sentiment. The feedback on this feature referenced all the learning principles, except *authentic* and *learner-centered learning*. For example, one participant commented:

> *I like this feature as I think information flows in an easier way, because in class, whether we like it or not, there is always the feeling that the professor is talking to students; he knows more, he's teaching the material, there is always this connection. Commenting on social media platforms is more like talking through; it's much easier, much more flowing*.

Such comments hint at how communication between professors and students improved through shared comments. This shifted the perception of students from being *talked to* by professors in a classroom setting to *talking through* the online platform, thus improving the flow of communication. This supports the *facilitating learning* principle. On the negative

side, some students mentioned that comments did not add value to the learning process, as they would interact with the material and analyze it without reading through the comments.

Overall Tool Help with Studies 84% of the students expressed a favorable view of the potential support of the proposed features in their studies, while 6% had a negative perception, and 9% were neutral. The students related this dimension to all learning principles, except *learner-centered learning*. For example, one student stated:

> *Overall, I like these additional tools provided. I particularly like the fact that it is now possible to share existing and new materials with all my classmates and link them to a particular part of the course and to comment on the shared material, ask a question, and another student answers the question through another comment.*

This revealing comment hints at the cooperation between students that is possible when using the various tool features. This reflects a direct connection to the *collaborative learning* principle. The main negative aspect students mentioned was the lack of additional information displayed on who shared the material.

Exploring Material Within Moodle The ability to examine the related material within Moodle generated 78% positive, 13% neutral, and 9% negative sentiments. On the positive side, this feature was one of the few that triggered the *authentic learning* principle. For example, a student mentioned:

> *It is good because sometimes we don't get the concept directly from the course material or from the book, and we need further resources. One way to study is actually by connecting the things you learn to your life, to an image, to a story, creating a scenario. This feature does, in a way, create a scenario; it creates a connection. If I am, for example, learning something about keeping records, or in accounting, I am keeping track of overhead, material and everything, and there is another link of how, let's say, Bugatti keeps track of their purchases, how they outsource, how they don't outsource, that would certainly keep the concept in my mind. This helps us remember more, and when we're doing a test, you can easily recall things and relate them to questions in the exam.*

Such recreation of real-life stories reflects the *authentic learning* principle enabled by the explicit links of the knowledge graph between social media material and formal courses. In this case, the knowledge graph played a significant role in the automatic filtering, selection, and display of relevant material on course LMS pages, based on curriculum concepts. Some students had a negative perception of this feature, mainly related to the interface and the way material exploration windows were activated within Moodle.

Bookmarking Social Media Materials to Formal Courses The bookmarking feature had the highest percentage (20%) of neutral perception, with 68% positive, and 12% negative. From a student perspective, the data shows that this feature referenced all the learning principles, except *interactive* and *authentic learning*. On the positive side, one student stated:

I like the fact that I can bookmark anything I find interesting while working online. It automatically saves the link for me, and I can come back to it whenever I want. I would know under which topic this material will appear in the courses because I am the one who is specifying and controlling the concepts related to the bookmarked material. It is like having my personal input to not only what we learn in courses but also in which part of the course we should expand on having additional material.

This statement highlights that bookmarking and linking material can turn a previously rigid online platform, controlled mainly by professors, into a dynamically adaptive environment to student input. The perception of having personal input into the curriculum and having a student-based material organization reflects the presence of the *learner-centered learning* principle. On the negative side, some of the concerns that emerged from bookmarking materials were related to the relevance of some materials to course coverage.

Aggregate Social Bookmarking Browser The aggregate social bookmarking page showed the lowest overall sentiment (37%), with 63% expressing positive sentiments and 2% expressing negative sentiments. The remaining students had neutral opinions. This feature resulted in references to all learning principles, except *authentic learning*. On the positive side, one of the students reflected:

This page is interesting as it centralizes the communication around the shared material in a dynamic way. You can see the comments on the material from all students in one place automatically appear here. Also, the recent bookmarks help you keep track of any new trending topic related to our courses. You can start watching videos and see the comments directly from there!

This comment supports the *interactive learning* principle. One interesting aspect of the presence of such a page is that students contrasted it with features provided by other tools they were using. For example, some students perceived this page negatively since it listed social media materials in a decontextualized manner, compared to the *material exploration within Moodle* feature, which listed the materials directly within the course page and close to the related topical contexts. Another negative point raised by several students was the lack of search functionality, while others felt that this page was tailored more for professors to monitor content rather than for students to browse. Other students also highlighted they should be able to vote on essential content or to track the most visited materials.

Discussion and Conclusion

Findings

Performed in the context of an undergraduate IS course of a business school, the pilot evaluation provided several insights. The processing of the concepts and relations in the knowledge graph used by 180 students during bookmarking activity revealed the majority (around 68%) of shared materials from social media linked to concepts and courses beyond the IS discipline. This hints at the knowledge graph-based tool potential to integrate transdisciplinary social media materials with formal courses. This approach may assist curriculum

designers in how to bundle concepts, not around hard course boundaries, but around meaningful connections socially constructed by students.

The semi-structured interviews conducted with 33 students fleshed out their opinions of the tools' potential to facilitate the six learning principles that support constructivism in online environments (Huang, 2002). Students valued how the tools had an impact on providing *high-quality learning* by breaking down course silos and offering a more relevant learning experience. Some students perceived the conceptually connected materials as a bridge between courses that, in their view, are traditionally designed and delivered in isolation. The tools also had an impact on enabling a more *authentic learning* process by drawing on contextualized examples from social media content that students appreciated. This contextualization was performed by explicitly connecting curriculum concepts to real-life stories and content through the knowledge graph. Students valued the ability to see what their friends shared in their educational space and *collaboratively* discussed and resolved problems by commenting on the material. Students expressed how the learning was *facilitated* by communicating through the tools rather than being talked to by professors. There was also an appreciation for the ability to personally contribute to the development of curriculum concepts, supporting the *learner-centered* principle. Tracing trending material on course pages provided students with an improved level of *interactivity* with social media features and manipulation of shared materials.

Contributions

This work provides three main contributions to the field. First, it proposes a framework and a set of tools to support educators and students in integrating and accessing transdisciplinary social media content within formal courses. The framework is a step toward integrating community-driven interests exchanged on social media, with formal courses that traditionally follow rigid curriculum-driven design (Greenhow & Lewin, 2016; Mott, 2010). With the challenges identified in building home-grown social learning platforms, it was evident that such systems have a low chance of institutional support due to their lack of control, similar to what is offered by traditional LMS, and lacked meeting the expectations of students compared to what is offered by mainstream social media (Anderson & Dron, 2017). The approach in this paper demonstrated how the semantically connected knowledge graph data enabled tool development—giving students the best of both worlds—social media, and LMS platforms. The tool features enabled students to share and socially bookmark materials across several topics in their curriculum, browse, and explore shared materials from within their institution's LMS around topical coverage, defined by their standard curriculum. This contributes to joining students' preference in using social media for sharing and interacting with content, with their preference in using LMS features in organizing content around their topical coverage (Jong et al., 2014).

Second, it provides initial evidence on the potentials of knowledge graph-based tools in supporting social constructivism in online learning platforms. The proposed approach offers the means for educators to transform the content of their formal courses with detailed and explicit concepts, which serve as building blocks for students to integrate and access social media material. The tools aid students in constructing social media links with formal courses and in accessing the linked material in their learning contexts. This extends the potential of enabling students to perceive relations between ideas, concepts, and fields (Sie-

mens, 2005), and building connections between real-world knowledge sources and formal classroom knowledge. A contribution of this work, which builds on the six core principles of constructivism in online learning environments (Huang, 2002), is that knowledge graph tools provide concrete and traceable means for preserving the concepts and connections constructed by students around their formal learning settings.

Third, this work offers a novel knowledge graph supported by an openly accessible ontology on the web to establish semantic connections between social media and formal course entities. The ontology contributes to extending research efforts in designing knowledge graphs to support learning environments (Dietze et al., 2013; Nahhas et al., 2018; Pereira et al., 2018). The openly accessible ontology encourages related work to reuse and extend the data graph on the web to reinforce data-driven connections across systems going beyond the boundaries of educational institutions. This can lay the foundation for the creation of a global knowledge graph that integrates the social and learning aspects captured from online learning environments. With appropriate privacy and data access rules, learners can potentially tap into learning networks spanning beyond the boundaries of their institutions. The fusion of social and educational web of data can facilitate the creation of distributed connected knowledge (Downes, 2010), achieving "globally connected schools" (Richardson & Mancabelli, 2011) through the development of richer and more engaging personal learning networks (Han & Ellis, 2020; Kennedy, 2018).

Limitations and Future Research

It is essential to highlight some potential limitations of this work. First, the experiment and data collection were performed in the context of one course in the IS domain. This can potentially introduce certain biases due to the background of enrolled students as well as the topics covered in the course. Performing additional experiments in other course domains and involving students from several faculties could be valuable for this research. A second limitation of the study is that the analysis does not capture the professors' perspectives. Their feedback on the tested tools could deepen the potential analysis of knowledge graph use in this context. A third research limitation is students did not make use of all the social features developed in the tool set. Hence, the tested tools require further development to capture the increasingly sophisticated social interaction features of online social media platforms. A fourth research limitation is the current study does not analyze the implications of crowdsourcing ontology concepts by students, which may cause the vocabulary to run wild. It is worth analyzing the potential ways the same concept may be labeled differently by several students and investigating how to control such cases.

With respect to future work, this research could be extended in several directions. First, an interesting angle is to analyze how the program goals and learning objectives are met when the curriculum concepts are dynamically constructed. During the construction process, it is expected that gaps are filled or new differences emerge, based on new learning goals. A second interesting direction is to extend the current analysis by designing a test to objectively evaluate the impact of the approach on the development of students' competencies and learning perceptions. This may involve collecting and analyzing system logs that provide data for such a study. In addition, further statistical analysis can be performed to study the significance of variations in the tools' support of constructivism's six learning principles. A third potential research interest is to investigate the value of showing the underlying

ontology schema to students and its impact on the way students represent and interact with concepts. This can be performed through a controlled experiment to compare the behavior of students who have access to the schema versus those who don't when interacting with concepts. A fourth potential research direction is to extend the current approach to allow students to explicitly label the types of links between social media materials and concepts. This opens up the opportunity to perform a further qualitative evaluation of knowledge graph links created by students.

Conclusions

The increased adoption of social media for educational purposes still poses a challenge for educators and students in integrating their formal curricula with online materials. One of the reasons behind this challenge is the complexity involved in socially constructing explicit links between transdisciplinary social media content and formal courses that traditionally follow rigid curriculum-driven design (Greenhow & Lewin, 2016). Inspired by the role of organizing knowledge around concepts to support learning (Jonassen, 2006; Medin, 1989), and knowledge graphs evolution on the web pushing for the creation of semantic connections at the data level (Berners-Lee et al., 2001; Fensel et al., 2020; Hogan et al., 2021), this work focused on addressing the following research question: to what extent do knowledge graph-based tools help students with integrating and accessing transdisciplinary social media contents in formal courses and contribute to constructivism in online learning environments?

This paper proposed a knowledge graph-based framework to integrate and access social media contents in formal courses. The framework includes a novel Socio-Education knowledge graph supported by an ontology to provide explicit concept-driven links between social media entities and formal courses. Three knowledge graph-based tools were developed to aid students in constructing social media links with formal courses through the Socio-Education knowledge graph and to access the linked materials in their learning contexts. The pilot study provided initial evidence of the potential support of students with the integration and access of transdisciplinary social media materials in formal learning management systems. In addition, the preliminary analysis of students' feedback hinted at promoting constructivism in online learning environments. With the increased sophistication of data and knowledge representation on the web, knowledge graphs will continue to evolve to provide smarter opportunities for students and educators to connect and engage in more immersive learning environments.

Appendix—Evaluation Protocol

*[**Action**] (1) Start the voice recorder. (2) Click on the "red dot" in CamStudio to start recording.*

3. Ask the following questions, then pause and wait for the answer after each question.

1. **Generic Questions**..

[***Question***] Do you think that courses at the School of Business are always up to date? Why?

*[**Action**] Go to this link and play it*: https://www.youtube.com/watch?v=Gc2en3nHxA4.

[***Question***] How do you think this could be relevant to what you are studying at the School of Business? In which course do you think this could be taught?

2. **Social Bookmarker**..

Now I am going to show you again how bookmarking online material works.

*[**Action**] (1) Go to this link*: https://www.youtube.com/watch?v=HlBBdoYbzYA*(2) Click on the "Bookmark Material" button within the browser. (3) Show the title, material type, cover concept, and description fields.*

[***Question***] Do you have any questions about this feature before you bookmark a video?

*[**Action**] Go to this link*: https://www.youtube.com/watch?v=Gc2en3nHxA4.

[***Question***] Please bookmark this link.

[***Question***] What do you think about this feature? Why?

3. **Social LMS Explorer**..

Now I am going to show you again how you can explore shared material within Moodle.

*[**Action**] (1) Go to*http://lms.aub.edu.lb. *(2) Go to the Information Systems Course. (3) Click on the "Extract Material" button within the browser. (4) Click on the "Related Material" button next to "Chapter 1—The Importance of MIS." (5) Click on "Moore's Law Got Me" video (without playing it). (6) Show briefly one article. (7) Give the mouse to the student and give them time to explore Moodle with the new buttons.*

[***Question***] Please check the material related to "Chapter 9—Business Intelligence Systems." What do you think about this feature?

[***Question***] What do you think about the comments related to the "Big Data - Tim Smith" YouTube? What do you think about having comments like this shared with other students and professors?

[***Question***] Please go to this article: "The Deciding Factor: Big Data Decision Making Capgemini Worldwide." A student shared this. Based on her input, this article will appear within Information Systems AND Management courses. What do you think of this?

[***Question***] How do you think those tools can help you in your courses at the School of Business? Why?

4. **Social Bookmarks Aggregator**..

*[**Action**] Go to*: https://linked.aub.edu.lb/apps/socialbookmarks/*and give the student the mouse to browse it.*

[***Question***] What do you think about this page? Do you find it useful? How? Thank you!

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