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Social practices in teacher knowledge creation and innovation adoption: a large-scale study in an online instructional design community for inquiry learning

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Abstract
Social practices are assumed to play an important role in the evolution of new teaching and learning methods. Teachers internalize knowledge developed in their communities through interactions with peers and experts while solving problems or co-creating materials. However, these social practices and their influence on teachers' adoption of new pedagogical practices are notoriously hard to study, given their implicit and informal nature. In this paper, we apply the Knowledge Appropriation Model (KAM) to trace how different social practices relate to the implementation of pedagogical innovations in the classroom, through the analysis of more than 40,000 learning designs created within Graasp, an online authoring tool to support inquiry-based learning, used by more than 35,000 teachers. Our results show how different practices of knowledge appropriation, maturation and scaffolding seem to be related, to a varying degree, to teachers' increased classroom implementation of learning designs. Our study also provides insights into how we can use traces from digital co-creation platforms to better understand the social dimension of professional learning, knowledge creation and the adoption of new practices.

Keywords Online communities · Learning design · Social practices · Knowledge appropriation model · Digital traces · Inquiry-based learning

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Introduction

Despite the benefits that educational innovations may entail, their adoption in the classroom is known to be challenging, as this requires teachers to embrace new teaching and learning practices (Webb and Cox 2004). For example, while student-centered pedagogies, like inquiry-based learning (IBL), have been shown to lead to benefits for student learning, they require a major shift in perspective in the role of the teacher, in how students approach the task and how they need to be supported. When introducing IBL, teachers not only need to acquire an understanding of IBL pedagogy but also develop new teaching practices. This, in turn, requires creating new knowledge of how IBL's theoretical ideas can be contextualized and integrated into each particular teaching setting.

In this paper, we focus on knowledge creation through online professional communities of teachers. The use of digital co-creation platforms to develop materials is widespread in teacher education (e.g., Vuorikari et al. 2011). These communities are characterized by the fact that individual learning (e.g., about IBL pedagogy) is embedded within collective knowledge advancement that is driven by a shared commitment to the further development of the domain (Wenger 1998). As a result, shared practices and a shared repertoire around those practices develop, often reified as documents, materials, lesson plans, and other artifacts. As professionals get access to, make sense of, adapt, and internalize this knowledge that has been developed in the community, they contribute at the same time to building the collective knowledge base. These online communities have often been analyzed under the framework of knowledge-building communities (Pata et al. 2016; Teo et al. 2017), or online knowledge communities (Jeong et al. 2017). Yet, while this knowledge-oriented perspective has traditionally been important in the CSCL community (e.g. Suthers 2006; Jones et al. 2006; Fischer et al. 2007), it has been targeted by few empirical studies, especially in large-scale environments (Jeong et al. 2014; Wise and Schwarz 2017; Rosé et al. 2020).

In the next section, we will advance our theoretical perspective on this issue, which has emerged from research on the Knowledge Appropriation Model (KAM; Ley et al. 2020), a model to describe social practices of knowledge creation and learning to be expected in such professional settings. To study such KAM practices in online professional communities, we chose Go-Lab, a community with more than 35,000 teachers registered as of the end of 2019. Go-Lab is devoted to promoting IBL and provides teachers with an authoring tool (Graasp) for the co-creation of Inquiry Learning Spaces (ILSs): pedagogically structured learning environments that can contain online labs, apps, and resources (Pedaste et al. 2015; Rodríguez-Triana et al. 2014). Within this online community, teachers cooperate and collaborate to develop knowledge by creating or adapting ILSs for their own use in classroom settings. Thus, Graasp offers the possibility to study how new knowledge is created and the potential role of social practices in the adoption of inquiry, on a large scale.

The application of the KAM model to the particular case of Go-Lab also allows us to make another contribution. While the analysis of online knowledge creation as a form of teacher professional learning is widespread, there is to date little evidence of the impact of those practices in actual classroom adoption. Since Graasp supports and traces not only ILS co-creation but also its implementation with students in the classroom, we have identified those KAM practices that we deem especially important for such ILS adoption. By analyzing a large number of collaborative artifacts and traces in Graasp, we also advance the CSCL research agenda on computational approaches to understand collaboration and its effect in communities of learners (Wise and Schwarz 2017).

Therefore, the current paper explores how the relationship between these social practices and the adoption of educational innovations can be traced in an online community. Our ultimate goal is to better understand which social practices seem to be more strongly related to actual classroom implementation, in order to design collaborative functionalities in such platforms that would encourage social learning and knowledge creation, which eventually lead to changes in professional practice.

The rest of the paper is structured as follows: the next section summarizes related research on learning and knowledge creation in communities. We next describe the methodology, the particular context where it took place, and the results of our study, followed by a discussion of its findings, limitations, and implications. We conclude the paper with a reflection on how this line of research contributes to the CSCL community, and future work in this direction.

The role of social learning and knowledge creation practices in adopting pedagogical innovations

Among the many factors involved in the adoption of pedagogical innovations like IBL pedagogy, social learning has been shown again and again to have an important, positive impact: the more teachers are involved in professional networking and collaboration, the more likely they are to apply such pedagogies (e.g., OECD 2014). Similarly, teacher collaboration and efficacy are correlated, and seem to predict student achievement (e.g., Lee et al. 1991). When teachers collaborate with peers (Blumenfeld et al. 1994) or with experts (e.g., Schenke et al. 2016), their understanding develops and new classroom practices emerge.

In a Community of Practice, such individual learning is embedded within collective knowledge advancement (Wenger 1998): interacting with peers or seeking help from more expert colleagues, not only contribute to individual learning, but also to advancing new pedagogies as a collective concern. Shared practices and a shared repertoire around those practices develop (often reified as documents, materials, lesson plans, and other artifacts), as professionals get access to, adapt and internalize knowledge that has been developed in the community. Such social practices involve goal-directed actions, and are mediated by technology and artifacts that have been created as systems of knowledge in the community (Hakkarainen 2009). Participants of that community develop capacities in applying this knowledge to their own practice.

This leads to a materially embodied perspective of knowledge where material or epistemic artifacts mediate human activity and thereby become bearers of human knowledge themselves, as has also been recognized in Knowledge Building or Trialogical Learning (Paavola and Hakkarainen 2014). When discussing the Knowledge Forum, the inquiry learning environment used to support knowledge building theory, Hakkarainen (2009) remarks: "Knowledge Forum may be seen literally to carry knowledge concerning inquiry processes" (p. 220), and this materialized knowledge may be more important than the theory to explain it. In our case, Go-Lab incorporates knowledge about IBL pedagogy, and what is maybe even more important: as teachers design ILSs in Graasp, they create and re-create this knowledge every time they develop an ILS.

This mediation and re-mediation involved in the knowledge creation process in professional learning has been recently described in the Knowledge Appropriation Model (Ley et al. 2020). This model identifies learning and knowledge creation practices (in organizations, communities, groups and individuals) that can be observed in the context of new innovative practices being created and adopted. The model is based on sociocultural models of learning (knowledge maturation and scaffolding) and explains how these processes are interconnected in professional learning, leading

to knowledge appropriation. In this sense, KAM focuses not only on engagement in the community, but on the creative process to create models that enable new processes of participation and reification, as well as in community alignment through production of artifacts, establishment of common ground and contribution towards shared visions (Wenger 1998).

In the context of KAM, knowledge maturation is understood as a social learning process that transforms knowledge (often embodied in artifacts) from the individual to the community level (by individuals being connected to and participating in social groups or communities, see Maier and Schmidt 2015). The co-construction of artifacts, as found in many models of knowledge creation and knowledge building (Stahl et al. 2014), is central to this phenomenon. Scaffolding describes a related social learning process whereby individuals develop expertise through guided interactions with experts or more advanced peers, who help them to internalize the knowledge that has been developed by the community. In this way, the focus of KAM is on the collaborative construction of knowledge and the role of the individual (whose learning is embedded within such co-construction) who contributes to this collective advancement of knowledge (see also Cress and Kimmerle 2008).

Previous research on professional learning (Ley et al. 2020) has derived up to 12 learning and knowledge creation practices assumed responsible for the successful adoption of an innovation. These practices have also been validated in the context of teacher professional learning (Leoste et al. 2019):

- *Knowledge maturation* practices lead to the transformation and maturation of knowledge (Fig. 1, left). Starting from concrete experiences during work, a teacher may express the idea of engaging in a new method of teaching and learning, often creating an artifact, which is shared with a group of people (sharing) and further transformed (co-creation) into more mature knowledge, so that it is reusable by other teachers outside the narrower community that created it (formalization). Eventually, knowledge might reach a status in which it becomes standard, for example, in terms of national curricula or being incorporated in widely-accepted training material for beginning teachers (standardization).
- *Knowledge scaffolding* practices explain how this knowledge about innovative teaching or learning methods is applied in concrete working situations and how professional learners receive support in this application (Fig. 1, right). The starting points often are individual experiences at work (e.g., experiencing certain problems when applying such knowledge in the classroom). The teacher may request help regarding this problem, and other peers or experts provide guidance towards a solution. Then, as the teacher acquires competence, peers and experts fade their support.
- *Knowledge appropriation* practices (Fig. 1, center) are assumed to underlie both maturation and scaffolding. They explain how knowledge that is collectively developed (knowledge maturation) is then individually applied. These practices describe how individuals are made aware of knowledge about typical problems in the domain and possible solutions (create awareness), and how the community maintains a shared understanding about these problems and their solutions. Later, teachers can adapt those solutions to new situations according to the local circumstances, and establish some form of validation (e.g., gathering experiences or formal evidence about the success and impact of the solution).

Collaborative online platforms are increasingly being used in the collaborative design of innovative teaching and learning scenarios, and it is possible to find evidence of the aforementioned social practices by observing the traces collected in those platforms. For example,

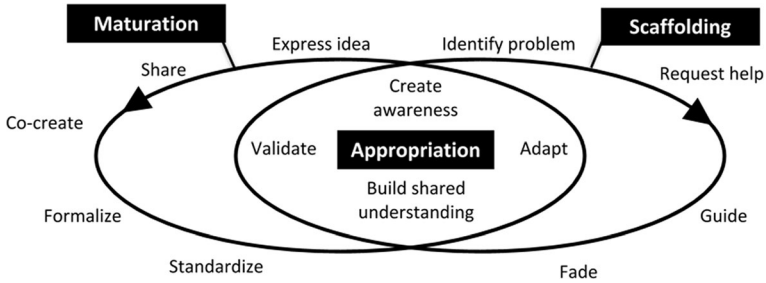

Fig. 1 Knowledge appropriation model (KAM; Ley et al. 2020)

in Graasp we can observe how learning designs for IBL are collaboratively created and later applied in the classroom. In this way, an understanding of the role that the learning and knowledge creation practices have in the process of innovation adoption can be gained. These insights may also help us suggest ways to improve such collaborative platforms.

In this paper, we use KAM as an analytical framework to guide the analysis of how knowledge appropriation practices and the adoption of IBL teaching practices can be traced in a large-scale collaborative online platform. Our study shows how KAM helped us describe the case of the Go-Lab initiative to support IBL, and elicit indicators to follow these practices and the adoption of the underlying IBL pedagogy.

Context: the Go-Lab ecosystem supporting inquiry-based learning (IBL)

Inquiry-based learning (IBL) has long been associated with positive student outcomes, such as improved ability to apply scientific thinking, or increased knowledge retention rates (Seymour et al. 2004). However, wide-scale adoption in practice by teachers remains a major challenge in this area (Fairweather 2008; Henderson and Dancy 2011). Because students need effective guidance in the process of inquiry (de Jong et al. 2013; Mayer 2004), IBL is a notoriously demanding practice for teachers. In that sense, support for the design or creation of IBL activities is one of the orchestration needs most often mentioned (Slotta et al. 2013).

The Go-Lab initiative aims to support teachers and students in the adoption of IBL pedagogies, especially in the area of STEM, by offering a technological ecosystem around the notion of Inquiry Learning Spaces (ILSs): pedagogically structured learning environments that can contain online labs, apps, and resources (Pedaste et al. 2015; Rodríguez-Triana et al. 2014). As illustrated in Fig. 2, ILSs are typically visualized as web spaces structured according to the different phases of an inquiry to be defined by the teacher, and enriched with multimedia content, inquiry apps (e.g., to support hypothesis formulation) and labs. In an ILS, learners are supported by navigating to these spaces as they go through the different inquiry phases, and interacting with the multimedia content and apps available there.

The Go-Lab ecosystem is made up of two platforms: Golabz,[1] a repository where teachers can find apps, labs, ILSs ready to be used, and support materials; and Graasp,[2] a platform for ILS authoring and implementation, as well as for community gathering. Additionally, there is an online help desk where teachers can request support, and specific face-to-face training events that are organized at the regional, national and international levels.

[1] Go-Lab repository: https://www.golabz.eu.
[2] Go-Lab authoring tool (Graasp): https://graasp.eu.

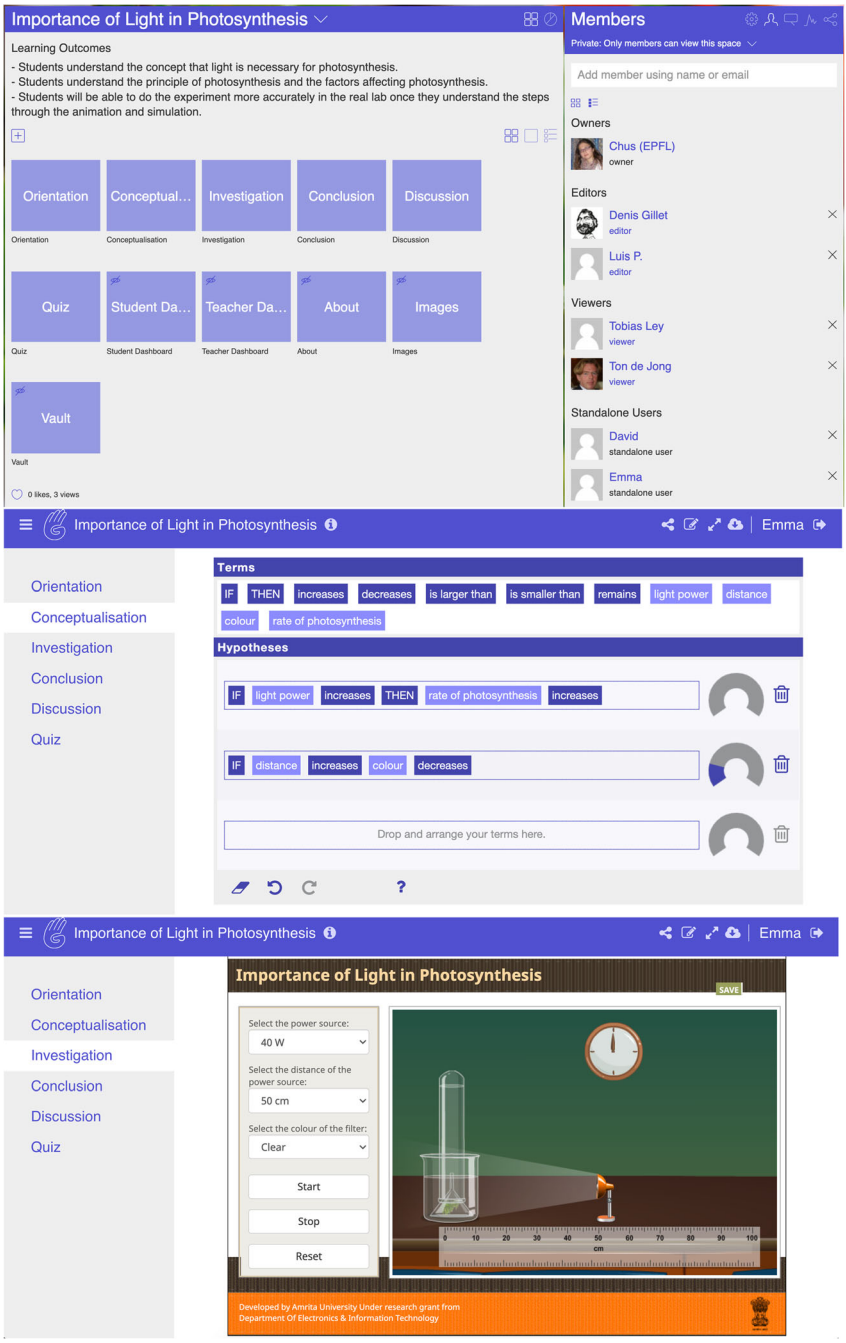

Fig. 2 On top, example of an ILS authoring view: the left panel contains the overall description, the phases to be shown to the students and additional spaces where the teacher can arrange additional material (those marked with a crossed eye are hidden to the students); the right panel lists the different members of the ILS. In the middle and bottom images, the same ILS is shown from the student view: left-side tabs named as inquiry phases, an inquiry app (Hypothesis Scratchpad, in the middle image) and a virtual laboratory (Amrita University's photosynthesis lab, in the bottom image)

Graasp was originally designed as a general-purpose digital education platform supporting personal, collaborative, and inquiry learning, as well as knowledge sharing. Throughout several EU projects related to the Go-Lab initiative (including Go-Lab, Next-Lab, and GO-GA), Graasp has been extended to be exploited specifically as the Go-Lab authoring and learning platform. From 2009 through December 2019, Graasp reached 37,380 registered teachers and more than 100,000 students, coming from 152 countries. Looking at the demographics, the United States leads the ranking of countries with most teachers (7.11%), followed by Switzerland (7.03%), Spain (4.56%), Portugal (3.80%) and Ukraine (3.16%). On the other hand, if we look at the origin of teachers who have *implemented* ILSs in the classroom, the ranking by country varies: Switzerland (13.04%), Estonia (11.33%), Portugal (10.76%), Spain (7.46%), and Netherlands (6.89%) occupy the top positions. Although the classification of primary, secondary and higher education teachers is not provided by all users, out of 3457 teachers who provided this information, 29.71% belong to primary education, 63.47% to secondary and 16.78% to higher education. It should be noted that teachers may be teaching at more than one level at the same time (i.e., there could be overlap between these groups).

Graasp can thus be considered a large-scale online community dedicated to IBL, and with an average of more than 250 visits per day in 2019, it can also be considered very active. However, despite a large number of ILSs being created on the platform, the adoption rate is 5.76%, meaning that only about one in 17of the ILSs that have been (co)created by teachers have potentially been used in a classroom (and can therefore be considered an "implemented" educational innovation). Similarly, in terms of teachers, 50.51% were involved in the (co)creation of an ILS, while only 12.47% contributed to ILSs that were finally implemented. Graasp shares this phenomenon with other social, community-based online systems, where nominal participation is large but active contributions are much rarer (Imroz 2019).

With the current study, we aim to shed light on how the adoption rate (associated with classroom implementation) is influenced by the social practices of teachers involved in the platform. In the Study section below, we detail how we applied KAM to guide the identification of indicators for these social practices in the Go-Lab initiative, and to explore how different ways of co-creating contextualized pedagogical knowledge (reified into ILSs) are associated with classroom implementation.

Research questions, hypotheses and methodology

Against the aforementioned research background and context, this paper thus tries to answer the following research question: *how are social practices (as defined by KAM) during the design of an ILS, related to the adoption of ILSs by Go-Lab teachers?* Three hypotheses can be derived from that question, according to KAM:

- Hypothesis 1: the adoption rate of an ILS will increase across the stages of knowledge maturation
- Hypothesis 2: the adoption rate of an ILS will increase when scaffolding is provided by experts
- Hypothesis 3: the adoption rate of an ILS will increase when knowledge is appropriated

Given the scarcity of communities of practice where we can analyze social practices, we opted for researching these issues through a case study. The large-scale reach of the Go-Lab platform

as an authentic setting where data was being collected "in vivo", led us to adopt an observational approach to avoid interfering in the potential usage of the platform. Moreover, due to the scale of the platform, using a systematic quantitative approach for data gathering was crucial to extract initial conclusions that applied to the whole community being studied. According to Wenger (1998), in a community of practice, negotiation of meaning involves shared histories of engagement through forms of participation and reification. This set of shared actions and artifacts is accumulated over time to act as resources for further meaning negotiation. Similarly, the Knowledge Maturation framework (Maier and Schmidt 2015) assumes the development of knowledge artefacts as indicative of knowledge maturation practices. Therefore, tracing social practices through artifacts (in this case, the ILSs) seems aligned with both frameworks.

In our study, we used the ILS as the main unit of analysis, as it constitutes the central shared artifact around which collaboration of teachers is organized. ILSs are at the same time products of knowledge creation and maturation in the community, and they also scaffold teachers' implementation of IBL in the classroom. In the context of the Go-Lab community, this is operationalized through teachers' active involvement in the (co)creation of (digitally-reified) IBL activities in an ILS, that can be shared with other practitioners, collaboratively edited, and implemented with students.

More concretely, our case study analyzed the data for the ILSs created from November 2015 (when ILS reuse, authoring and implementation actions began to be consistently tracked in the platform) to December 2019.[3] Since we were interested in tracing the collaborative practices of teachers, only ILSs where teachers were involved in the design process were considered in the analysis (i.e., ILSs exclusively created by research project members or for training purposes were not included), resulting in a dataset of 40,235 ILSs. In addition to this artifact-oriented analysis, we also looked at the number of teachers involved in different kinds of KAM social practices, to assess how widespread these practices were among Graasp teachers.

Several assumptions were made to interpret the data available in the platform logs. We considered *experts* to be those registered users who are tagged as Go-Lab, Next-Lab, or GO-GA project members (as they are assumed to be more knowledgeable about IBL than other teachers who may have entered the platform through participation in training and other means). The rest of the users registered in the Graasp platform were considered potential *teachers*. An ILS was considered *implemented* in the classroom (i.e., adopted) when more than 10 "student-mode users" are registered to it. This empirical rule of thumb stems from conversations with teachers using the platform, as their classes have around 20 students on average, and teachers often report their students to be using the platform in groups of 2 or more people per computer (Rodríguez-Triana et al. 2015).

Regarding data analysis, basic descriptive and exploratory statistics were used. First, indicators developed as markers for the presence of different KAM social practices (see the following section), which were automatically coded for each ILS. Then, counts of ILSs (and rates of their implementation in classrooms) were calculated, for different levels of maturation, appropriation and scaffolding. Furthermore, chi-squared tests of independence and logistic regression modeling were used to ascertain the potential association between the KAM-related practice indicators and ILS implementation (and the relative strength of such associations).

[3] Please note that figures and analyses may vary slightly from other Go-Lab or Graasp studies due to the different datasets selected for each study.

The data used for this study was collected in Graasp in compliance with the European General Data Protection Regulation (GDPR). After being informed about the platform terms and conditions, by signing up, Graasp users agreed on the potential use of their data for research purposes. In addition, the dataset obtained from Graasp was anonymized. First, only the data relevant for the study were selected from the Graasp database, namely: ILS identifiers, members, predecessors (i.e., in case the ILS was a copy of a previous one), creation and implementation dates, as well as number of student views; user identifiers and type (i.e., teacher or expert); and user actions per ILS. Then, all the identifiers were hashed to ensure anonymity during and after the analysis. Thus, with such a dataset, it was possible to distinguish experts and teachers, and consistently identify users across ILSs.

Study: Tracing KAM practices and adoption in Go-Lab

ILSs constitute the shared repertoire of artifacts created by the Go-Lab community. Collaborative actions performed with an ILS (such as sharing, co-creation, and reuse) constitute the history of engagement that is accessible through the platform's log of actions related to the ILS. We were especially interested in the KAM practices connected to ILSs and how teachers were contributing to knowledge maturation, scaffolding and appropriation. Below, we describe how these practices can be monitored. Table 1 summarizes the KAM practices in the context of the Go-Lab initiative, and more concrete platform indicators are listed in Tables 2, 4 and 6.

Knowledge maturation practices With the help of the Graasp platform, teachers can *create* ILSs, starting from an IBL template. Later, teachers can decide to invite peers as members of their ILSs (i.e., inviting other teachers to be owners, editors or viewers of the ILS) for either *sharing* or *co-creation* purposes. Once an ILS is ready, teachers can publish it, to make it available for other teachers. This process also involves an expert review that provides feedback via email about how to *formalize* the ILS. *Standardization* could happen, for example, if ILSs were widely taken up by other teachers at the national or international level to address specific parts of the curriculum.

Knowledge scaffolding practices Teachers may *request help* from experts using the help desk available in the ecosystem, where a set of experts is available to resolve doubts and provide *guidance*. Additionally, teachers often address their trainers or national coordinators face-to-face or via email, videoconference or social media, or by inviting them as members of an ILSs, to have a look, comment or even *edit* the ILS. In some cases, experts also accompany teachers the first time they implement an ILS in their classroom. Then, to encourage teachers to solve their own problems and be autonomous, expert support *fades* progressively, by reducing the face-to-face support and the interventions in the ILSs. It should be noted that, in Graasp, teachers can work on the same ILS for long periods of time, or they can make copies of it and continue working on those new versions. Thus, fading can happen within a single ILS (e.g., if an expert provides guidelines at the beginning of the ILS creation, letting the teachers work on their own afterwards), or across different ILS versions (i.e., if an expert has been involved in a previous version of an ILS, but not in the current one).

Knowledge appropriation practices Teacher *awareness* comes from four different sources: the teachers themselves, searching and browsing through the Go-Lab repository and the

Table 1 Knowledge Appropriation Model and the corresponding practices in the Go-Lab initiative. Practices mapped onto monitorable metrics in Graasp appear in bold

Social practices		Metrics used in Go-Lab
Knowledge maturation	Express (individually)	**Creating an ILS** (neither shared with other teachers nor published)
	Share	**Sharing an ILS with peers** (i.e., inviting other teachers to be owners, editors or viewers of the ILS)
	Co-create	**Co-editing of an ILS by several teachers** (i.e., actively participating in the ILS's creation in Graasp)
	Formalize	Formalizing an ILS
		Publishing an ILS
	Standardize	Taking up of an ILS at a larger scale across the community
Knowledge scaffolding	Request help	Making help desk requests
		Making requests face-to-face, via email
		Sharing an ILS with an expert (i.e., inviting experts to be owners, editors or viewers of the ILS)
	Guide	Providing help desk support
		Providing support face-to-face or via email
		Editing of an ILS by an expert (i.e., active participation by an expert in the co-creation of the ILS in Graasp)
	Fade	Gradual decrease in expert intervention in the development of an ILS
		Expert intervening in previous ILS versions, but not in the current one
Knowledge appropriation	Create awareness	Browsing around the repository & support material
		Receiving system recommendations
		Hearing about a peer's experience
		Subscribing to the newsletter
		Registering in the online community
		Participating in training events
	Adapt	Making adaptations to an ILS created by another teacher
	Validate	Refining an ILS after being implemented
		Sharing experiences about the implementation of an ILS
		Gathering data about the success of an ILS implementation
	Build shared understanding	Peers and experts participating in discussions
		Creating reified artifacts (e.g., ILS phases versus IBL process)
	(Resulting knowledge appropriation)	**Adapting and reusing an ILS created by/with another user as the basis for a new design**

Table 2 Adoption status (ILS implementation) for each knowledge maturation level

Maturation level	Indicator	Adopted	Not adopted	Adoption rate
Express (individually)	ILSs created, but not shared with teachers or published	1199	34,300	3.38%
Share	ILSs shared with teachers, but not co-created or published	585	2598	18.38%
Co-create	ILSs co-created with teachers, but not published	253	533	32.19%
Formalize	ILSs published for the community	337	430	43.94%

support material; the technical ecosystem, which provides teachers with recommendations about relevant apps, labs, resources, and so forth; peers, who share their knowledge or experiences using communication channels inside and outside the ecosystem (e.g., face-to-face or in social media); and experts, who keep teachers updated about new apps, labs, ILSs, functionalities and events through the newsletter, the online community and, especially, through training events. Once aware of the available support, teachers can *adapt* existing ILSs (created by other teachers or experts) to their own educational contexts. Thus, we consider ILS reuse (i.e., creating an ILS that is a copy of a previous ILS) and later edition or use with students, as a proxy (albeit an imperfect one) for the fact that knowledge appropriation has taken place.

Although the ecosystem supports communication between users, most of the discussions between peers to reach a common *understanding* about the learning context and the ILS take place outside of the Go-Lab platforms. For example, the review process before ILS publication triggers a (face-to-face or email) conversation between experts and teachers that not only leads to ILS refinements, but also improves the experts' *understanding* about teacher needs, usability issues, misconceptions and challenges for ILS adoption in the real classroom.

ILS *validation* usually takes place during the face-to-face training events (outside of the Go-Lab technological ecosystem) where practitioners are invited to share their experiences implementing ILSs in the classroom. Through iterative refinement the validation of the content of an ILS also increases as copies (and copies-of-copies) of it are modified and implemented.

Innovation adoption in the Go-Lab initiative While there are different degrees of adoption (e.g., teachers can use IBL practices, labs, or apps independently), in this paper we focus on the potential usage of full ILSs in the classroom, since ILSs reify the overall objective of the Go-Lab initiative: the IBL pedagogical approach combined with apps, labs, and multimedia resources that contribute to scaffolding students in the inquiry learning process. It is worth noting that only the teachers involved in an ILS can implement it in the classroom (other teachers have to create their own copy of the ILS before implementing it). The adoption rate was thus calculated as the number of ILSs used in the classroom divided by the total number of ILSs created by teachers.

Despite the fact that these practices involve both face-to-face and computer-mediated interventions, in this paper we focus only on those that are supported (and traceable) through the Go-Lab ecosystem. In fact, since the Go-Lab repository does not require logging in, no evidence can be obtained about the "create awareness" actions carried out by specific teachers there. Therefore, only the practices mediated by the Graasp authoring platform were taken into consideration in the analyses below (see practices highlighted in bold in Table 1).

Results

Hypothesis 1: The adoption rate increases across knowledge maturation stages

Knowledge maturation is a collective knowledge creation process in which the knowledge of a domain is developed systematically and artifacts related to that knowledge are created alongside it. With the first hypothesis, we explored whether the adoption of an ILS was related to those knowledge maturation practices. Specifically, we checked whether the fact that an ILS was considered being at a higher stage of maturity was related to its eventual adoption in the

classroom by its co-creators. In order to test this first hypothesis, each ILS was assigned to one exclusive knowledge maturation category according to the indicator scheme shown in Table 2. Then, for each maturation category, the rate of ILS adoption was calculated.

Our results show that knowledge maturation is strongly related to later adoption (i.e., implementation) of the ILS in the classroom. The difference between sharing and co-creating is especially remarkable. While sharing and co-creating both entail involving a limited group of teachers in the ILS, the adoption greatly increases when those other teachers actively participate in the design. Aside from these descriptive results, a chi-squared test of independence also indicated a strong association between ILS maturation levels and adoption: χ^2 (3, $N = 40{,}235$) = 4276.6, $p < 0.001$. Figure 3 presents a graphic illustration of these results, where we can see that ILSs at higher levels of maturation were implemented more often than expected.[4]

Looking at the number of teachers involved in these practices, we can also assess how widespread these knowledge maturation practices are among those 20,064 Graasp teachers who (co)created ILSs. Table 3 shows the number of distinct teachers who participated in ILSs of the different maturation levels. Since a single teacher can be involved in multiple ILSs, there can be overlap in the teachers involved in the different levels. A large majority of teachers individually created ILSs, but appreciable minorities were also members of ILSs with higher maturation levels (in total 7049 or 35.13% of teachers either shared, co-created or formalized ILSs). It is also worth noting that increasing percentages of these teachers were involved in ILSs that were implemented (rightmost column in Table 3), thus suggesting again that there is a relationship between these maturation practices and the adoption (i.e., classroom implementation) of the practices reified by the ILSs.

Hypothesis 2: The adoption rate increases when scaffolding is provided by experts

In sociocultural conceptions of workplace learning, it is assumed that scaffolding is a way that individuals develop expertise by being guided by more knowledgeable others. In Graasp, scaffolding can be observed to some extent in the role that experts have in the creation of ILSs. Thus, we explored whether the adoption of an ILS was related to scaffolding practices. Specifically, we analyzed whether *the adoption rate of an ILS increased with increasing levels of expert scaffolding* (namely, not scaffolded, help requested, guided, faded). To test this hypothesis, each ILS was characterized by the type of role that experts had had in its creation. Finally, we calculated the rate of adoption for each scaffolding category, as reported in Table 4.

We found that expert scaffolding in Graasp is also strongly associated with later adoption. Interestingly, collaboration with experts appears to be a strong driver for adoption, even more than collaboration with peers (cf. the adoption rates of the shared and co-created maturation levels in Table 2). On the other hand, the rate of ILS adoption with prior scaffolding (i.e., faded support) was comparatively low (even if it was still larger than the expected value). All in all, as illustrated in Fig. 4, a chi-squared test of independence strongly rejected the null hypothesis

[4] The term "expected frequencies" here is used in relation to the chi-squared ($\chi 2$) test of independence, and refers to the values we would expect to see if the null hypothesis is true (i.e., if there were no relationship between KAM practices and adoption, in the population of ILSs). To calculate the expected frequency for a specific combination of categorical variables, we multiplied the column total (e.g., adopted ILSs) by the row total (e.g., reused ILSs), and divided by the sample size (in this study, N = 40,235 ILSs).

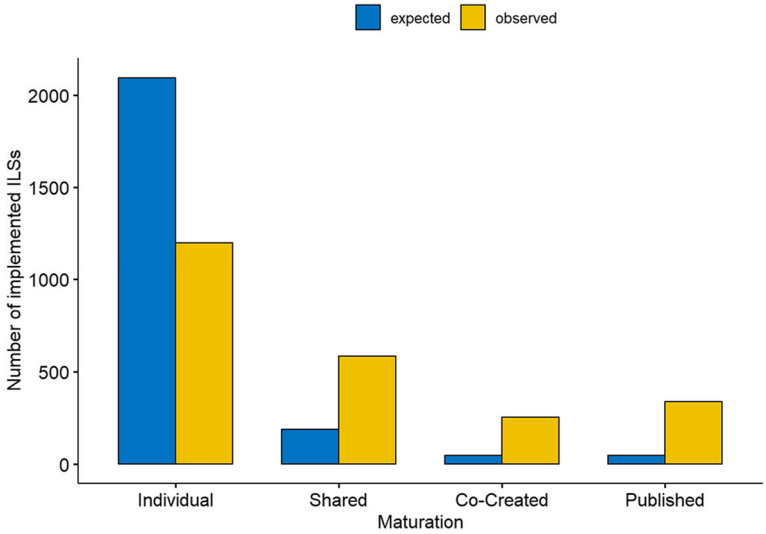

Fig. 3 Expected versus observed number of implemented ILSs per knowledge maturation level

(i.e., independence of scaffolding level and classroom adoption): χ^2 (3, $N = 40{,}235$) = 3177.08, $p < 0.001$.

Looking at the numbers of teachers involved in ILSs showing traces of these scaffolding practices, we see that teacher participation in scaffolded ILSs was uncommon but not rare. While there is overlap among the teachers who had ILS at different scaffolding levels, a total of 3796 teachers (18.92% of the 20,064 Graasp teachers who created ILSs), participated in ILSs that had undergone some kind of scaffolding. As we can see in Table 5, higher levels of scaffolding were increasingly rare. We can also see how increasing proportions of teachers involved in help-seeking and guided ILSs, participated in implemented ILSs at those levels. Interestingly, this trend was again less apparent for the ILSs in the fading stage. These results suggest a relationship between these scaffolding practices and classroom implementations, although the relationship does not appear to be a linear or monotonic one.

Hypothesis 3: The adoption rate increases when knowledge is appropriated

KAM assumes knowledge appropriation to be a key process for both knowledge maturation and scaffolding to take place. It explains how collective knowledge (the ILSs and the knowledge about IBL, Graasp, Go-Lab and the Go-Lab community at large in our case) is related to individual learning. Appropriation, therefore, should also be strongly related to

Table 3 Teacher involvement ILSs at different knowledge maturation levels and in implemented ILSs

Maturation level	Teachers involved (% of total teachers, $N = 20{,}064$)	Teachers involved in implemented ILSs (% of total teachers involved in ILSs at this level)
Express (individually)	16,330 (81.39%)	643 (3.94%)
Share	5175 (25.79%)	1624 (31.38%)
Co-create	2843 (14.17%)	1445 (50.83%)
Formalize	1307 (6.51%)	709 (54.25%)

Table 4 Adoption status (ILS implementation) for ILSs showing different knowledge scaffolding practices

Scaffolding categories	Indicator	Adopted	Not adopted	Adoption rate
No scaffolding	ILSs created without any kind of expert involvement in the current version or previous versions	1550	35,330	4.20%
Help request	ILSs shared with experts, but not edited by them	363	890	28.97%
Guide	ILSs edited by experts	368	610	37.63%
Fade	ILSs with experts involved in previous versions, but not the current one	93	1031	8.27%

eventual adoption. Thus, we hypothesized that knowledge appropriation should be one of the determinants of adoption. In the current setup of the system, it was not feasible to gather data about individual practices of appropriation (creating awareness, sharing understanding, adapting or validating), and thus for this analysis we considered ILS reuse (and later editing) as a proxy for knowledge appropriation. Due to the importance of the social and adaptation aspect in the appropriation, we focused on whether an ILS was based on ILSs created by other users or in collaboration with other users, thus excluding ILSs that were created and reused by the same individual teacher (or ILSs that were not edited, i.e., that were prone to be just backup or test ILSs). Then, as shown in Table 6, we compared the rates of adoption for reused versus non-reused ILSs.

We found that knowledge appropriation in Graasp is also associated with adoption, with the adoption rates for reused ILSs being about four times higher than those created from scratch (or likely to be backup/demo copies). A chi-squared test of independence also rejected the null hypothesis (i.e., independence of appropriation and adoption): χ^2 (1, $N = 40{,}235$) = 1395.36, $p < 0.001$. Figure 5 represents the results of the chi-squared test.

Looking at the prevalence of these knowledge appropriation practices within the Graasp community (see Table 7), we can observe that most teachers (97.16% out of 20,064) created

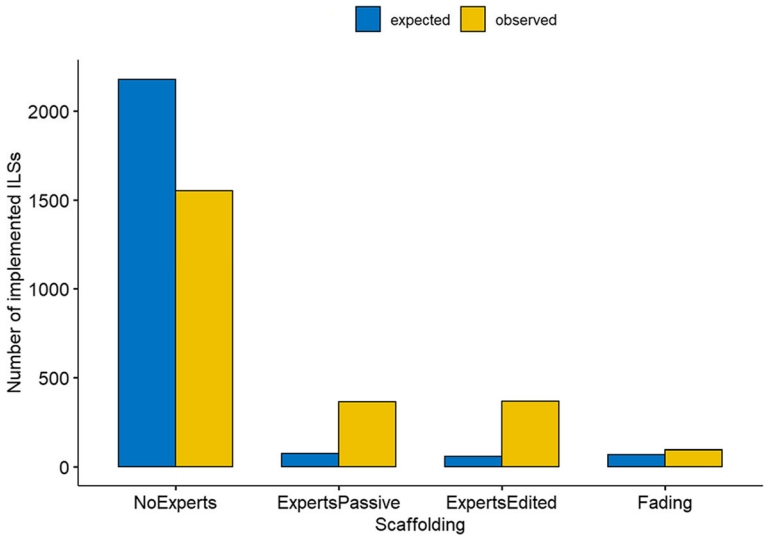

Fig. 4 Expected versus observed number of implemented ILSs per knowledge scaffolding practice

Table 5 Teacher involvement by knowledge scaffolding practices and ILS implementation

Scaffolding categories	Teachers involved (% of total teachers, N = 20,064)	Teachers involved in implemented ILSs (% of total teachers involved in ILSs at this level)
No scaffolding	18,581 (92.61%)	1816 (9.77%)
Help request	2274 (11.33%)	741 (32.59%)
Guide	1949 (9.71%)	1273 (65.31%)
Fade	659 (3.28%)	98 (14.87%)

ILSs from scratch. Nonetheless, about one in every eight teachers reused and edited previous ILSs created by other users, or created in collaboration with other users. Among these teachers, a higher percentage of those who reused ILSs ended up being involved in an implemented ILS. This suggests that there is a relationship between this appropriation practice and the adoption of ILSs in the classroom.

Relative association among knowledge maturation, scaffolding and appropriation

In order to perform an initial exploration of the relative strength of the associations between ILS adoption and the three different kinds of social practices targeted by our hypotheses (i.e., knowledge maturation, scaffolding, and appropriation), we trained a logistic regression model. Such a regression model tries to predict whether an ILS will be adopted or not, as a function of its levels of maturation (from individual to formalized), scaffolding (from not scaffolded to faded) and appropriation (not reused or reused). The results are summarized in Table 8.

We can observe that, except for certain forms of scaffolding (concretely, fading), all KAM practices were found to be significant (and positive) predictors of whether an ILS would be adopted in the classroom. For instance, along the maturation axis, we find that sharing an ILS with others multiplies the odds of adoption by 3.81, while co-creating the ILS with others increases the odds by a factor of 9. Knowledge scaffolding practices have a somewhat subtler effect, multiplying the odds of adoption by about three, and fading actually having a non-significant effect. Regarding appropriation, we can see that once the other KAM practices have been factored out, its effect is also positive and statistically significant, on average multiplying the odds of adoption by a factor of 3.86 when an ILS is reused and edited.

It is also worth noting that, as expected by KAM, the odds of adoption of an ILS increase with higher levels of maturation and appropriation. However, our observational study found that higher levels of scaffolding do not necessarily have higher effects on adoption (e.g., guiding or fading vs. requesting help), at least as traced by the Go-Lab indicators we had defined.

Table 6 Adoption status (ILS implementation) for ILSs showing knowledge appropriation (reuse and edition)

Appropriation categories	Indicator	Adopted	Not adopted	Adoption rate
No reuse	ILSs that are not edited/used copies of a previous ILS from other users	1649	34,919	4.51%
Reuse	ILSs that reuse and edit a previous ILS from other users	725	2942	19.77%

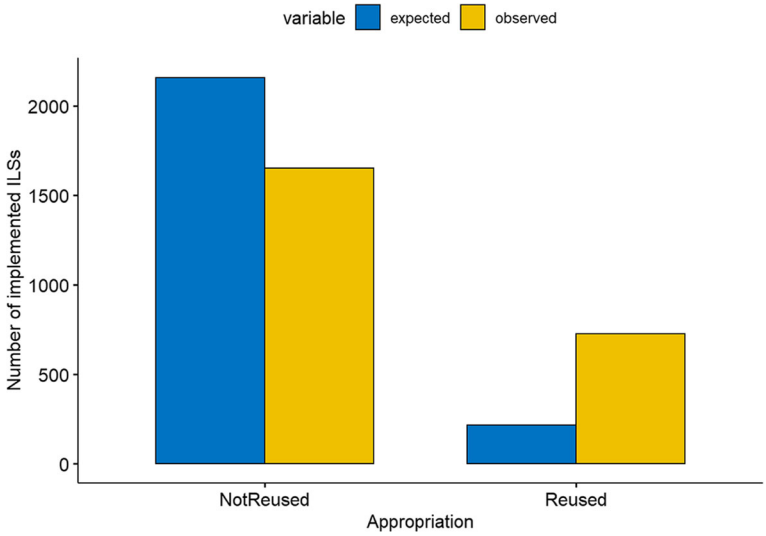

Fig. 5 Expected versus observed number of implemented ILSs per knowledge appropriation category

Discussion

Findings

In this study, we were able to map KAM practices (Ley et al. 2020) onto the case of Go-Lab, an online community of teachers using inquiry-based learning. While not all of these social practices were fully traceable (see Table 1), the data available in the authoring and learning platform allowed us to find indicators of several computer-mediated collaborative practices across 40,235 inquiry-based instructional designs (ILSs), and their eventual classroom adoption. The chi-squared tests of independence showed *significant associations between knowledge maturation, scaffolding and appropriation indicators, and ILS implementation*. A logistic regression confirmed that all three practices seem to contribute independently to later classroom adoption. Among these three types of KAM practices, knowledge maturation, which looks particularly at how teachers collaborate and refine ILSs, appears to have the strongest association with ILS implementation (as shown by the larger chi-squared statistic and logistic regression coefficients).

Knowledge appropriation was also found to be a significant predictor of later ILS implementation. Although our current operationalization of appropriation (based on reusing and adapting ILSs) tries to capture some of the social practices and teacher intentions when appropriating ILSs, it is still a rather generic measure, and further platform developments or research work could aim to untangle the different appropriation practices of validation,

Table 7 Teacher involvement in knowledge appropriation practices and ILS implementation

Appropriation categories	Teachers involved (% of total teachers, N = 20,064)	Teachers involved in implemented ILSs (% of teachers involved in ILSs at this level)
No reuse	19,494 (97.16%)	2643 (13.56%)
Reuse	2644 (13.18%)	1092 (41.30%)

Table 8 Coefficients of logistic regression model of adoption as a function of knowledge maturation, scaffolding and appropriation

Coefficients	Estimate	Odds ratio	Std. error	z-value	*p* value
Intercept (Individual, Not reused, Not scaffolded)	−3.58		0.03	−111.16	<0.001
Maturation (Share)	1.34	3.81	0.06	21.15	<0.001
Maturation (Co-create)	2.20	9.04	0.09	24.37	<0.001
Maturation (Formalize)	2.51	12.36	0.09	28.45	<0.001
Scaffolding (Help request)	1.15	3.16	0.08	14.40	<0.001
Scaffolding (Guide)	1.10	2.99	0.09	12.75	<0.001
Scaffolding (Fade)	−0.18	0.83	0.13	−1.48	0.137
Appropriation (Reuse)	1.35	3.86	0.06	23.69	< 0.001

building a shared understanding, etc. A possible analytical framework to use in this regard would be the uptake framework (Suthers et al. 2010), as knowledge appropriation could be evidenced by analyzing in more detail the interactions in Graasp when an ILS is taken up by other teachers and adapted to other educational contexts (e.g., to a different classroom, country or language). Furthermore, our present analysis narrows down the multiplicity of appropriation practices to just one: whether an ILS reuses and adapts previous material. Thus, a richer analysis of appropriation practices is needed, e.g., analyzing how teachers create awareness of existing content and materials for themselves (Michos and Hernández-Leo 2018).

Knowledge scaffolding also showed strong associations with ILS adoption in the classroom. This is somewhat aligned with previous studies that used self-report questionnaires (Leoste et al. 2019), in which scaffolding was found to be very important for teacher adoption of innovations. Yet, the apparent effect of different scaffolding practices (especially, fading) was not completely in accordance with the expectations set by KAM – which could lead to theoretical or operationalization advances in future research, either defining different kinds of fading (e.g., by looking at how far in the past the scaffolding happened), or by establishing more accurate platform-specific indicators of such fading. It should be noted that the present study uses a restricted view on scaffolding, looking only at the experts and their role. Certainly, scaffolding also plays a part when teachers of different expertise levels interact with each other. Thus, this kind of peer scaffolding in our analysis is hidden underneath the maturation practices (e.g., co-creation, in which peer guiding most likely plays an important role). The more precise disentangling of these practices, likewise, would need to be left to more detailed analyses looking at the content of the ILSs and the knowledge building dialogues that take place inside or outside the platform (Brown and Munger 2010; Galley et al. 2014; Hong and Scardamalia 2014; Michos and Hernández-Leo 2018).

Looking at the proportion of *ILSs showing traceable KAM practices,* we found that *such ILSs were not very frequent in the dataset* (11.77%, 8.34% and 9.11% of ILSs presented evidence of maturation, scaffolding and appropriation, respectively). Such low frequencies may have several explanations. On the one hand, this could be due to a lack of teacher awareness or expertise with the functionalities available in the platform, or the lack of opportunities to collaborate with others (e.g., in those cases where teachers may not personally know peers or experts in the platform). In this sense, the number of teachers that participated in ILSs at different levels of the KAM, paints a complementary (and perhaps more accurate) picture of these phenomena: at least 35.13%, 18.92% and 13.18% of 20,064 teachers in our dataset had participated in ILSs with some level of maturation, scaffolding or appropriation, respectively. These teachers were also generally more likely to participate in an ILS that was implemented in

the classroom (42.37%, 53.16% and 52.53% respectively, compared with the dataset average of 16.27% teachers who had participated in an implemented ILS). These data at the teacher level (cf. the ILS level) support the hypothesis that the social practices of those teachers might be behind the classroom adoption, rather than the high quality of particular ILSs.

While many ILSs were used by 10–25 different students, which is most probably a single class, multiple ILSs presented 25–50 or even more distinct students. These numbers, along with direct feedback from teachers, lead us to think that many of these ILSs were used repeatedly with different classrooms. Therefore, there could be cases where the teachers reimplemented the same version of their own ILS instead of creating a new copy of it for such a purpose. Thus, this usage of the platform could especially explain the relatively low number of detected cases where ILSs were reused, and/or scaffolding faded. Furthermore, we should not forget that several KAM practices happened fully or partially outside the platform. Thus, the evidence collected through Graasp only shows a part of the whole picture.

The results from the logistic regression show that *later KAM stages are not necessarily related to increased levels of adoption*, as illustrated by the case of scaffolding practices. While this finding could lead us in the future to modify the KAM itself or our expectations with regard to its practices, these results can also be due to several factors limiting the validity of our operationalization of the KAM using indicators available in the Graasp digital platform. Such confounding factors include peculiarities in teacher usage of the platform (e.g., as mentioned in the previous paragraph regarding ILS reimplementation), relative ease of use of different platform functionalities (e.g., sharing ILSs is very easy and effortless, while publishing is more time-consuming), or varying levels of user expertise (e.g., which teachers are aware of what functionalities available in the platform). Other limitations of the measurement instruments we used in this study include the fact that we compressed the whole history of an ILS's design into a single data point (i.e., we did not take into account the temporal evolution *within* each ILS). Thus, for instance, we did not detect the fading of scaffolding until that ILS was later copied and reused, and we did not explore whether the same ILS version was appropriated and re-implemented several times.

It should be noticed that the KAM-based logistic regression model reported in our results is still an imperfect predictor of whether an ILS (and the innovative teaching that it represents) will be implemented in the classroom or not (being about halfway between random chance and perfect predictions, in terms of area under the curve, AUC = 0.79). However, we would like to contend that it is actually surprising that such a simplistic model (based on simple, interpretable logical rules extracted from log data) can predict with any accuracy a complex phenomenon such as classroom adoption, in which many other aspects play important roles: institutional support, participation in training events or communities of practice, ICT skills and predispositions of teachers, and so forth. We believe this highlights the promise of the KAM for understanding both professional learning and the adoption of educational innovations, a line of investigation that should be expanded in future research.

Adoption of educational innovations In the Go-Lab community, out of 37,380 registered teachers, 53.68% were involved in KAM practices, and 8.74% were part of an implemented ILSs during the period of analysis. While these overall figures of adoption (and the other rates of participation in the KAM social practices) might seem low, they should be taken in the context of similar online communities where the barrier of entry is extremely low. We do not know of comparable figures from other authoring platforms that also enable classroom implementation and social practices among practitioners and experts. Yet, the eTwinning large-scale online teacher community had on average 27% of their registered teachers engaged in joint projects

and collaborations (Berendt et al. 2014), which could be seen as akin to our "social practices". We could also use as a reference different empirically-derived participation rules of thumb in social media and online communities, which suggest that between 50% and 90% of the users will not participate or contribute (Nielsen 2006; Brandtzaeg and Heim 2011; Antelmi et al. 2019). Hence, participation in Go-Lab is typical of (or higher than) platforms of its kind.

We should also take into account that, in the context of educational innovations, teachers are often encouraged to try new ideas and technologies. As a result, we often find educational digital platforms with a high number of registered users. However, many practitioners may not finally adopt those solutions due to contextual factors (e.g., lack of infrastructure in their schools), teachers' personal profile (e.g., lack of interest and curiosity on the innovation or digital skills), workload (e.g., lack of time, professional commitments), or even the curriculum itself (e.g., if their subject matter is not suitable to be learned through inquiry). Thus, while our findings about the social practices are encouraging, there are still many other obstacles which may interfere in the adoption of educational innovations, even before social practices (Ley et al. 2020) and other core aspects of communities of practice (Wenger 1998) play a role.

Limitations of the study

Our methodological choices (e.g., this being an observational case study) also bring with them certain limitations to the conclusions we can extract from our study. For instance, the fact that we do not have full sight of all relevant variables involved (as in an experimental setting), nor the richness of a more interventional approach. Also, the data gathering and analysis methods did not take into consideration the qualitative characteristics of the ILS (i.e., whether the ILS content was really representative of an IBL pedagogy). In addition, the assumption made to interpret the data available in the logs to detect ILS adoption was relatively superficial (based on an expected number of students per classroom implementation).

Another major limitation is that the present study relies only on the data already available about certain KAM practices mediated by Graasp, whereas additional interactions may have taken place through other face-to-face or digital channels. To overcome this 'streetlight effect' (Ochoa and Worsley 2016), it would be necessary to design ICT tools bearing in mind what needs to be tracked in order to study users' social practices, as also mentioned in the workplace learning analytics literature (Ruiz-Calleja et al. 2017). Moreover, it would be necessary to gather additional evidence from other physical and digital spaces where the social practices take place (cf. multimodal learning analytics, see Ochoa and Worsley 2016).

Implications

Despite the aforementioned limitations of our study, we can extract from it a number of interesting implications and lessons. In the context of Go-Lab, knowing that KAM practices are aligned with higher ILS adoption can help in supporting teachers in the future. For instance, the identification of key social practices could guide future platform development to refine or extend the existing functionalities in Graasp, for example, facilitating discussions or helping teachers find other relevant peers or experts (Laurillard 2009), helping practitioners to communicate and expand their networks (Jeong et al. 2017), or promoting not only the engagement but also the imagination and alignment aspects of the community of practice (Wenger 1998), e.g., encouraging the ILS co-creation and the exchange of teaching

experiences after the implementation. Also, TEL solutions could contribute to raise awareness about these practices (e.g., making their indicators part of the user profile) or provide actionable feedback about which social practices could help them, depending on their particular needs (e.g., what to do when teachers want to create their first resource, vs. who they can contact when they have doubts).

The positive association between KAM practices and ILS adoption could also inform existing strategies for teacher professional development in IBL (Maaß and Doorman 2013). For example, mentoring and teacher training activities could raise awareness and equip teachers with the skills and opportunities to benefit from these social practices, as already suggested by Leoste et al. (2019). Furthermore, teachers could profit from micro-level mechanisms for teacher collaboration within an institution to spread pedagogical innovations at the local level (Vuorikari et al. 2015).

The lessons above could benefit other IBL and TEL initiatives that seek to understand practitioners' motives to participate in communities of practice, fulfill their specific needs, and build and maintain a thriving community of users.

Conclusion and future work

While social practices are considered crucial in teacher ongoing professional learning, their implicit and informal nature make studying them rather challenging. In this paper, the Knowledge Appropriation Model (KAM) helped us to define traceable indicators of social practices that could then be related with the adoption of IBL in the classroom, through the Graasp authoring and learning platform. The descriptive and exploratory analyses of the dataset supported our initial hypotheses: higher levels of maturation, scaffolding and appropriation are connected with ILSs adoption rate. This positive association between KAM practices and IBL adoption could help to enrich existing strategies for teacher professional development in IBL (Maaß and Doorman 2013), and to inform authoring platform design.

This paper contributes to the CSCL field at different levels. From a theoretical point of view, this paper helps to better understand the relation between knowledge building processes and social practices (Hakkarainen 2009; Fischer et al. 2007), and it contributes to the validation of the KAM model. In terms of the context it studies, this paper addresses workplace learning and communities of practice, a context targeted by comparatively few studies (especially in such a large scale), despite prior interest shown by the CSCL community (Suthers 2006; Jones et al. 2006; Fischer et al. 2007; Jeong et al. 2014; Wise and Schwarz 2017; Rosé et al. 2020). From a methodological and disciplinary perspective, this paper contributes a multidisciplinary work that combines analytical and interpretative approaches (Wise and Schwarz 2017). More concretely, it uses computational data gathering and analysis methods to assess the applicability, in an authentic setting, of a theoretical model (KAM) coming from interpretive social psychology studies. Regarding implications for practice, in light of the positive role that social practices seem to play in knowledge building (and, as we saw in our study, in the adoption of new professional practices), it is important to emphasize how crucial it is to design digital platforms for communities of practice bearing in mind such social practices (Hakkarainen 2009; Laurillard 2009).

Nevertheless, more research is needed to understand how KAM practices can be effectively measured, and what relationship they have with knowledge building and innovative practice adoption. To reach that goal, future work should make use of mixed data gathering and analysis methods, as recommended by several authors within CSCL (Martínez et al. 2006; Jeong et al.

2014). For example, in line with our present focus on the learning artifacts (i.e., the ILSs), there is a need for qualitatively analyzing the ILS contents to better assess knowledge acquisition and skill development of teachers. Also, it would be necessary to explore other theories and models using the teacher as the main unit of analysis. This would enable the extraction of community and network attributes to further study the knowledge building process (Fischer et al. 2007; Wenger et al. 2011). For instance, the use of community analytics (Klamma 2013; Jeong et al. 2017) could contribute to guide further analyses of the Go-Lab community focusing on the teachers themselves, how they move from individual to collaborative interactions, and how these interactions develop over time (Imroz 2019). From a network analysis point of view, integrating social network analysis (Jan et al. 2019; Saqr et al. 2020), social learning analytics (Shum and Ferguson 2012), and cluster analysis could help us understand the social practices and the role that experts play in them (Martínez et al. 2006; Risser and Bottoms 2014). Finally, including additional data sources beyond the technical ecosystem (e.g., recording the discussions during teacher training sessions, or gathering the teachers' perceptions about their learning experience) would significantly enrich the initial quantitative estimations reported in our study, as already illustrated by Leoste et al. (2019).

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