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Boundary Objects in Collaborative Work and Learning

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Abstract. Boundary objects are artifacts, processes, concepts and other entities that provide bridges across boundaries and act as shared references that are meaningful for learners and collaborators with different backgrounds. In this paper, we explore cooperation in a cross-disciplinary and cross-cultural context, focusing on the opportunities for learning that arise at different boundaries and on corresponding boundary objects to facilitate both collaboration and learning. We present and discuss a study we conducted within a Cooperation Technology course. The discussion provides implications for collaboration support across boundaries, including insights on why they are important, how to facilitate their creation, and how to use technologies for that. The implications are formulated as instruction for designing university courses, but can be used in a wider context.

Keywords: cooperation technology, boundary objects, collaborative learning, course design

1 Introduction

Significant parts of course assignments and projects at universities are done in groups in order to promote collaborative learning and to prepare students for team-based activities in a workplace. Participants of the collaborative activities often have different backgrounds, for example, in terms of studied discipline and culture, schedules, level of engagement and interests. On the one hand, this may facilitate a

creative process and innovative ideas through the 'symmetry of ignorance' (Fischer 2005; Fischer et al. 2007). On the other hand, cooperation problems among the students are rather common and often lead to frustration and disruptions in the learning process (Anisetty and Young 2011; Shuangyan et al. 2010).

Starting from the core notion of *learning communities* (Wenger 2000; Fischer 2001), we investigate if *boundary objects* (objects that have meaning across different cultural, professional or other backgrounds) can help to improve collaboration and learning (Star and Griesemer 1989; Arias and Fischer 2000; Star 1989). In this paper, we apply the concept of boundary objects in a university course. Our main research objectives in the present study were the following:

- to analyze the usefulness of different types of boundary objects in different collaborative and technological settings
- to explore opportunities and challenges for collaborative learning that arise when using boundary objects
- to develop a set of implications and recommendations for using boundary objects in course design

The paper is based on a Cooperation Technology course at the Norwegian University of Science and Technology that integrates lectures with three practical tasks in which the students had to collaborate in different settings to create shared artifacts, and thereby construct new knowledge. Cooperation was supported with a variety of tools that we will hereafter indicate with the generic term *cooperation technology*. In the paper, we discuss the outcomes of the course and our experience, focusing on how students supported their cooperation across boundaries and used specific tools for that. The analysis is structured along categories of boundaries. Based on this discussion, we outline implications for cooperation support across boundaries in a social learning system, such as why boundary objects are important, how to facilitate their creation and what technologies to choose to achieve more efficient collaboration and learning.

2 Background and Related Work

Boundaries arise from "different ways of engaging with one another, different histories, repertoires, ways of communicating and capabilities" (Wenger 2000). They are important to consider for supporting 'social learning systems' (Wenger 2000), because of the learning opportunities they provide and connections they create between different communities and groups. Boundary objects are critical since they provide bridges and have meaning across the boundaries of the individual knowledge systems, groups or sub-communities that join together for some purpose (Wenger 2000; Fischer 2001; Star and Griesemer 1989). Boundary objects serve groups or communities in situations where each participant has only partial knowledge and partial control over the interpretation of an object (Fischer 2001; Arias and Fischer 2000; Star 1989). In this way, boundary objects allow different knowledge systems and communities to interact by providing a shared reference that is meaningful within

both parts. Such objects perform a brokering role involving "translation, coordination, and alignment among the perspectives of different Communities of Practice" (Fischer 2001). Boundary objects are typically negotiated, dynamic and have emergent characteristics. Star and Griesemer (1989) define boundary objects as "analytic concepts of those scientific objects which both inhabit several intersecting social worlds and satisfy the informational requirements of each of them".

Traditionally, boundary objects have been studied in industrial contexts, for example, in cross-disciplinary design teams (Fischer and Ostwald 2005) and product development (Carlisle 2002). Boundary objects may take different forms and shapes, for example, information technology may act as boundary objects for transformational learning in a design laboratory, military and construction industry (Forgues et al. 2009). Gal et al. (2004) report how boundary objects are used to construct and communicate social identities in Architecture, Engineering, and Construction Industry.

There have also been some initiatives to study boundary objects in educational contexты, especially in a blended learning context (Laumakis et al. 2009). Examples of boundary objects mentioned in the literature include blended learning in its own right (Laumakis et al. 2009), "lesson study" – a "systematic investigation of classroom pedagogy conducted collectively by a group of teachers" which is an established practice in teacher communities in Japan and China (Tsui and Law 2007), tools supporting pedagogical intervention (Yiannoutsou and Kynigos 2013), evaluation framework for assessment of asynchronous learning networks (Laumakis et al. 2009), and products of group work. Boundary objects are often deliberately created or 'seeded' by collaborators. However, they may also appear through a collaborative process when the collaborators are facing boundaries. The value of using the concept of boundary objects in education is in improving design and analysis of learning communities and collaborative activities.

Different ways have been suggested for categorizing and grouping boundary objects. For example, Star and Griesemer (1989) suggest four categories of boundary objects: repositories, ideal type (i.e. atlas, diagram), coincident boundaries, and standardized forms. Carlisle (2002) argues that different types of boundary objects (such as repositories, standardized forms and methods, models, and maps) are required to overcome different types of knowledge boundaries (syntactic, semantic, pragmatic). Dirckinck-Holmfeld (2006) suggests a different categorization for boundary objects facilitating groups work: group products, ideal types of frameworks, concepts, models, standards and guidelines, and communication infrastructure.

Not all elements, standards, concepts, tools, artifacts and processes that support educational processes serve as boundary objects. Let us take an example of an established learning community or community of practice: a group of surgeons and interns at a university hospital. Both the experts and the learners follow the same established procedures and processes at the operating theatre. They use the same equipment and a specific 'jargon' not always understandable to outsiders/non-medics. They do not need boundary objects as they all share the same understanding and are situated within the same 'boundaries'. If a surgeon discusses a patient's computerized tomography scan with an intern, they will use an established medical terminology they both understand, and the scan does not serve as a boundary object.

At the same time, no workplace or professional community today is 'sealed' within its boundaries. Representatives from different disciplines and communities need to interact to obtain common goals, such as treating a patient. When the surgeon discusses the same computerized tomography scan with the patient in question prior to a surgery, explaining the details and using a language/discourse they both understand, it becomes a boundary object, having a shared meaning both to a medical professional and a layman. The patient also needs to understand and follow his/her part of procedures before, during and after the surgery, though he/she does not need to go into all the details of the surgical process. The surgeon may also ask an engineer or technician whether the imaging quality could be improved using the same computerized tomography scan as a boundary object between the communities of medical professionals and computer vision specialists. Therefore, artifacts, processes, standards and other types of boundary objects having a shared meaning across different groups or communities perform a brokering role. At the same time, as we could see from the examples above, the 'boundary' between different roles is fluid and may change depending on the context.

As most educational activities today happen in diverse, cross-disciplinary settings, (as opposed to the medieval guilds), it is important to understand how boundary objects work in different contexts. In this paper, we choose the framework explained by Wenger, since we believe it provides the most comprehensive characterization of boundary objects in learning communities. We also apply the framework originally developed for communities to student groups, as we consider groups as subjects within a learning community and a part of the activity structure as suggested by Engeström (1987). According to Wenger (2000), boundary objects can be classified into three groups: *artifacts*, *discourses*, and *processes*. *Artifacts* may be tools, documents, models, or virtual places that stand out from the others by having meaning across boundaries (Prasolova-Førland 2003; Wenger 2000). Typical examples of artifacts as boundary objects are medical records and architectural blueprints (Wenger 2000) or the computerized tomography scan in the example above. In our study, shared artifacts can be seen as physical representations of knowledge that a group of students collaboratively create during project work. Such artifacts become boundary objects if they are created by a group or a community and can be understood by all members of the community. This might be, for example, essays jointly written by a multi-disciplinary project group. *Discourses* represent a common language that the participants of a collaborative process can use to communicate across boundaries (Wenger 2000). Discourses are negotiated terms and language constructions that have the same meaning for all the participants. A typical example is six-sigma discourse at Motorola, i.e. widely adopted and recognized quality standards (Wenger 2000). In our study, discourses can be seen as the language the students used to communicate in synchronous discussions and by commenting upon the work done by others. *Processes* include negotiated routines and procedures that allow coordination across boundaries, independently by practices established within boundaries, typically business processes (Wenger 2000). In our case, processes are represented by rules and agreements that allow synchronizing schedules and coordi-

nating work styles of the individual students within and between groups as well as across countries and institutional boundaries.

The existing literature on boundary objects is typically focused on organizations and Communities of Practice. For example, Wenger uses examples of specialists and processes at Motorola and Xerox (Wenger 2000). When discussing boundary objects in Communities of Interest, Fischer and Ostwald (2005) talk about cross-disciplinary designer teams. The concept of boundary objects is rarely used in pure (not corporate or professional training) educational settings, for example, (Huang and Huang 2013; Beddall-Hill and Jonathan 2010), which can be seen as the major gap in the state of the art this paper attempts to fill. More work is done on exploring boundaries between institutions and communities (Nolen et al. 2011; Jansen et al. 2012). However, we are not aware of any systematic attempts to discuss the matter.

3 Study Settings

The present study is based on the data collected during the Cooperation Technology course at our university in autumn 2012. The study settings included a number of boundaries imposed by course design (e.g., specific challenges we imbedded into the tasks) and objects provided (e.g., specific collaborative tools) for the students. At the same time, we gave the students certain flexibility, for example, in structuring the collaborative process within the groups and in employing their own mechanisms and additional software tools. This allowed us to explore if both provided-by-course and chosen-by-students objects had the properties of boundary objects and how they were used on the group and on the community level.

3.1 Course Design

When designing the course, we pursued two goals, presenting the theory of cooperation technology and providing practical experience. The latter included three tasks that were designed to provide students with experience of different types of collaboration, different types of boundaries, and different technological settings.

The course has been designed upon consideration of two main pedagogical approaches (Fominykh et al. 2013). *Social constructivism* proposes that learners co-construct their environment and understanding together with their peers (Vygotsky 1978). *Reflective learning* implies that students learn by reflecting on relevant experiences (D. Boud et al. 1985). Correspondingly, the two main goals of the practical tasks were to provide experience of collaboration mediated by technology and an opportunity to reflect on how it evolves and how collaboration (and consequently requirements for technological support) changes depending on the characteristics of the work.

The three practical tasks accounted for 70% of the final grade. In each of the practical tasks, the students worked on construction of shared artifacts in different collaborative and technological settings (Table 1). Traditional lectures were used for

introducing core concepts. This basic knowledge was intended as a conceptual tool to be used and extended in the group project.

We used group-based evaluations for the practical tasks, which means that members of each group received equal number of points. In addition, after completing a task, each group submitted reflection notes. Towards the end of the course, the students wrote a final individual essay accounting for 30% of the final grade.

Table 1. Course activities and Tasks

	Task 1	**Task 2**	**Task 3**
Course activities	Collaborative writing + online presentation	Creating a language dictionary + a glossary	Collaborative writing + f2f/ online presentation
Types of collaboration and boundaries	Local group	Local group + local community	Local group + international groups
Assigned technology	vAcademia	LingoBee	Adobe Connect, Purot Wiki, Prezi
Main outcome of collaboration	Handbook of cooperation tools	Language dictionary + glossary of terms	Online media handbook on educational technology

3.2 Target Group

The study was conducted with 31 students taking the course. They had had different study backgrounds, as the course is elective and open for a wide range of study programs. Therefore, many students did not know each other and had different schedules. In addition, several participants were exchange students or had immigrant background.

For the practical tasks, the students were working in small groups (seven groups of 3–5 members in each). The students had the possibility to form groups themselves, while the remaining students were put together randomly. The majority of the students participating in the course had good knowledge of and experience in using software tools. In the beginning of the course, we conducted a short survey to identify, among other things, self-assessed cooperation skills of the course participants. The survey was answered by 14 students. The results indicated that 64% of the students agreed or strongly agreed that they had good cooperation skills in general, and 55% agreed or strongly agreed that they use many different cooperation technologies in their everyday life.

In Task 3, our students were collaborating with students from Tallinn University (Estonia) and University of Oulu (Finland). Groups of 8–12 members were formed for this task by joining original groups from each university. It should be noted that the participants from these three universities were rather different in their study background and motivation. The joint task was a part of a mandatory course “Learning Theory and Pedagogical Use of Technology” for the Finns, an elective evening course “New Interactive Environments” for the Estonians, and an elective on-campus course “Cooperation Technology” for our students.

3.3 Technologies

In this section, we will briefly present the technologies and tools that we offered to the students. Designing the practical part of the course, we considered that the students should experience different technological settings. Therefore, we varied the technologies and allowed the students to incorporate any additional tools. The tools we offered in the course were new for most of the students. It was intended to encourage discussion on the appropriate use of technologies, critical thinking, and reflective learning (David Boud et al. 2006). In such a way, the students were required to communicate intensively and cooperate in various technological environments to complete the tasks.

vAcademia. In Task 1, we used a 3D virtual world vAcademia for hosting student presentations (Fig. 2). This platform is designed for learning and has a set of dedicated tools for supporting several types of collaborative activities (Fominykh et al. 2014). vAcademia supports the sense of presence and workspace awareness. It has tools for brainstorming and for structured and uninhibited communication. However, the most distinctive feature of vAcademia is 3D virtual recording, which allows capturing everything in a given location in the VW in process, including positions of the objects, appearance and movement of the avatars, contents on the whiteboards, text and voice chat messages (Morozov et al. 2012). Similar functionalities were realized earlier in few VWs or desktop virtual reality systems. However, 3D recording was never developed into a convenient tool and never adopted for specific use as in vAcademia.

A user can attend and work at a recorded session, not just view it as a spectator. In addition, any recorded session can be attended by a group of users (which we did in this course). From the user point of view, 3D recording control is very similar to the regular video player. A 3D recording can be fast-forwarded and rewound, paused, and played again from any point of time. Of course, the recorded avatars would always act the way they were recorded. However, it is possible to use all the functionality of the platform for collaborative work within a recording. Moreover, a replayed 3D recording can be recorded again together with new activities. In such a way, new recordings and new content could be created based on the same original event.

LingoBee. In Task 2, we used LingoBee, a mobile app for user-centered situated language learning, available on Android phones. Ideas of crowd sourcing and social networking were used to collect, share and annotate the contributions of all learners in a shared online repository (SIMOLA 2012), as shown in Fig. 3. Language learners were able to create this repository of language elements collaboratively by adding entries, words or phrases, which could be enhanced by adding new descriptions and downloaded as favourites by other LingoBee users. Users could describe language elements using text and multimedia such as photos, audio, video, and web links. The repositories created by LingoBee could be accessed through a mobile device (for browsing, searching, rating as well as contributions) and through a website for browsing.

The co-created LingoBee repository could be considered as the artifact, and this could be shared among all users. Lingobee was designed to support collaboration

through a shared repository and the ideas used in social networking tools such as peer rating; thus providing a discourse and process for collaboration.

Purot Wiki, Adobe Connect, and Prezi. In Task 3, we provided a set of three tools for the students. Purot is a cooperation and learning platform based on wiki technology (http://purot.net/). It was offered for the construction of the shared artifacts as well as for asynchronous discussions and peer reviewing. In addition, it provided the basic information about the course, the task, and the participants. The resultant student projects were published on Purot as open resources, and it is now available at http://cocreat.purot.net/.

Adobe Connect is a collaborative tool for web conferencing and other online activities (http://www.adobe.com/products/adobeconnect.html). Access to several virtual rooms was provided to support synchronous online discussions.

Prezi is a cloud-based presentation software. It was offered for creating final presentations with the intention to stimulate collaboration and creativity during the process of preparing presentation material.

4 Group Collaboration in the Course Design

Each task of the course was designed to provide experience with a different form of collaboration, investigating three different types of boundaries. In order to support exploration and learning of different technologies, we designed the tasks around different types of cooperation technology, plus the students could adopt additional tools at their choice for some of the activities.

4.1 Task 1: Collaboration and Boundaries within a Group

The first task was centered on collaboration within a group and it gave us a possibility to explore boundaries between individual participants. The students enrolled for the course were from different computer-science related study programs, including both local and exchange students.

Each group needed to decide on what technologies to use for collaborative writing and create a shared repository to store data related to the task. These actions would allow the groups creating boundary objects of the artifact type. Students in most of the groups needed to get to know each other and learn about each other's understanding of the task and related concepts. In such a way, they would create a common language – a discourse type of boundary object. Finally, each group needed to decide on the work routines and coordination mechanisms, creating boundary objects of the processes type.

In *Task 1* each group was asked to create a handbook containing a description of at least 10 tools for cooperation, clearly specifying intended readers and selection criteria, and justifying the overall organization of the entries and their internal structuring. There was no restriction on the tools for internal cooperation and for the delivering format of the handbook.

The resultant handbooks of tools were evaluated by the course staff and in general met the course expectations, with some of the groups making a considerable effort in identifying the needs of the intended target group and searching for tools outside the most common ones (Fig. 1). Some groups focused too much on the layout, but generally, the handbooks showed satisfactory knowledge of existing tools and demonstrated a considerable increment of the knowledge that as course staff we tried to convey through the lectures.

Fig. 1. A screenshot of a handbook of tools for collaboration made by the students

The groups presented their handbooks to their peers and visitors during a virtual seminar (Fig. 2) held in vAcademia and created 3D virtual recordings of their presentations (Morozov et al. 2012). In such a format, a presentation is a performance that communicates a message and an artifact that contains data at the same time. This activity required the students to explore different forms of cooperation, mediation, and recreation of their handbooks in a new and different format (either 3D virtual recording or live 3D presentation).

Fig. 2. Student group presentation in vAcademia

4.2 Task 2: Collaboration and Boundaries between Independent Groups

The second task was centered on collaboration between groups, with each group acting as a single entity, but interacting with other groups by providing feedbacks. The boundaries in this context were between the groups that need to understand each other's work to make a meaningful annotation or build on an artifact produced by another group. In order to provide this type of experience and to challenge the students with such boundaries, we designed a task where they could interact with other groups, but still producing shared artifacts within their initial groups.

In these settings, the students were working on *Task 2* where they had to use a mobile app LingoBee designed to capture language and culture related content in a situated context (http://simola.org/lingobee/) for producing (a) a dictionary of Norwegian phrases and (b) a glossary of cooperation technology terms (Fig. 3).

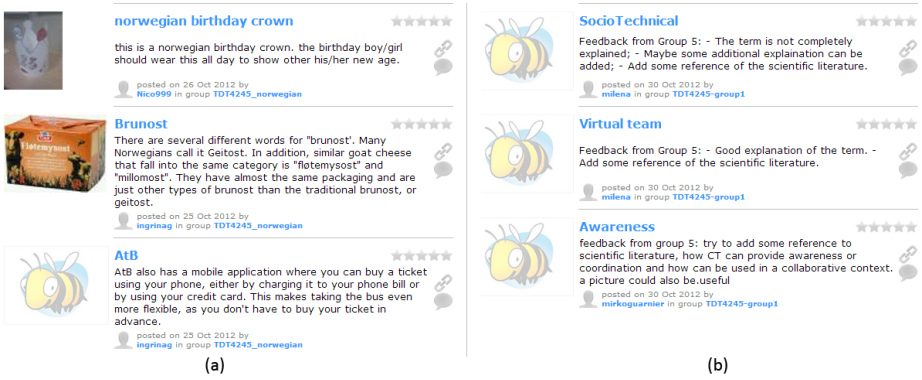

Fig. 3. Boundary Object – artifacts for Task 2 using LingoBee

Task 2 (a) was designed for a startup phase to learn the tool. The students had to create entries individually in a crowd-sourced dictionary and then comment and improve each other's entries and rank the best ones. For (b), each group had to create an initial draft of the entries in a repository visible only to the group. Then, all the entries were made public, and the groups had to comment on other groups' contributions and revise their own based on the feedbacks.

Sub-task (a) represented a typical scenario of usage for LingoBee (could have benefited from support for mobility); sub-task (b) was purposefully designed to stretch the usage boundaries of the tool. Feedback capabilities were not presented explicitly to the students, as reaching an agreement was expected to be challenging.

The cooperation required in Task 2 was rather complex, including cooperation within groups, across groups, and within a learning community. Collecting entries for the Norwegian dictionary could also potentially have led to cooperation with the local community.

LingoBee was designed for collaborative construction of language elements where one learner can add a new description to the contribution of another as in the case of "brunost" shown in (Fig. 3, a). Similarly, in Task 2 (b), the learners were asked to

provide feedback across the groups (an example is the term ‘Socio Technical’ where the entry says that it is feedback from group 5), to improve the description and thus the common understanding of the terms (Fig. 3, b).

The tasks were designed in a way that imposed a process of communication and coordination. In addition to this, the tool itself was designed to support specific collaboration processes. In this case, the construction of the artifacts was through learners contributing new entries as well as adding new descriptions or feedback to existing entries. The cloud-based repository provided access to all users to the repositories created by their own groups as well as the other groups (unless access was restricted through password protection).

4.3 Task 3: Collaboration and Boundaries between Joint Groups

Finally, the third type of collaboration we consider happened when groups were merged into a larger group and worked towards a common goal. In this case, the merged entities needed to not only understand the work of other entities, but also to establish a common practice to be able to work together. In order to let the students experience this type of complex collaboration, we designed a task where they could interact with other groups more intensively and produce shared artifacts together.

In order to implement these settings, we designed *Task 3* in which the students participated in a joint activity that was designed and conducted by the EU LLP CoCreat project (http://www.cocreat.eu/). This activity lasted five weeks and brought together 68 students from Tallinn University, University of Oulu, and our University. All the activities in Task 3 were conducted distantly. For our students this task represented an occasion to put into practice the knowledge gained during the two previous tasks. By cooperating with students with different backgrounds, they were expected to meaningfully and creatively apply this knowledge in a domain (education) that was outside their area of expertise.

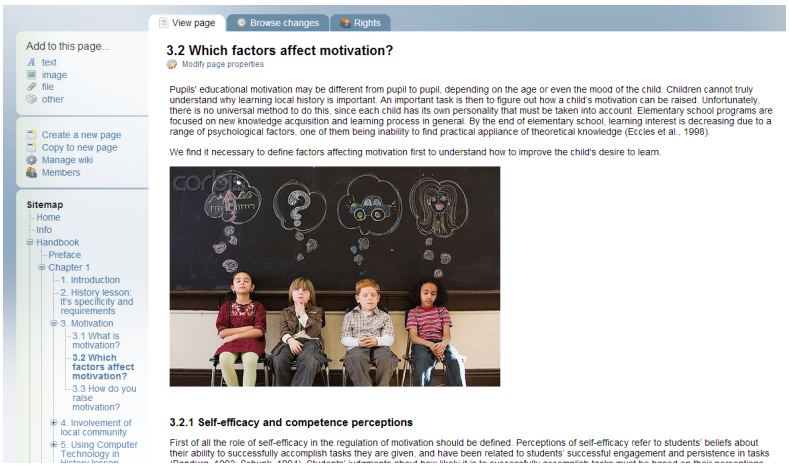

Fig. 4. A screenshot of a media handbook chapter made by the students

The joint activity consisted of several tasks aiming at creating a multimedia book. For this task, larger international groups were formed from local groups. Each of seven international groups consisted on three sub-groups (one from each participating university) and worked on one media chapter. Students were expected to base the contents of their chapter on given scenarios that represented real-life challenges of supporting learning with technology. Each chapter became a deliberate solution to the given challenge (Fig. 4). The quality of the resultant handbook chapters was assessed as satisfactory. The main challenges in this task were related to the international and distant collaboration.

5 Methods

5.1 Data Collection

The data were collected from the direct observation of students' online discussions, the virtual artifacts that they produced in each task (including automatically logged data), and their feedback in the form of group reflection notes, individual essays, questionnaires, and semi-structured interviews. The questions at the interviews were related only to Task 3. The main data source for this paper has been the groups' reflections notes, as they provided impersonal and the most complete picture of the group work.

Following the reflective learning approach (D. Boud et al. 1985), we aimed at promoting rethinking of the experience to learn from it. In such a way, collaborative writing and delivering reflection notes after each task was an important part of the learning design and mandatory for all groups. In order to scaffold the reflection process, we provided a template for the notes of each task, pointing out specific issues to consider, including the following:

- the flow of work during the task
- how different types of collaboration were affected by the technology used
- tradeoff between creativity and efficiency
- strengths and weaknesses of particular tools, including those provided by the course and selected by the student groups

The notes were written collaboratively in each group, so that the students had to discuss their experience. The groups invested different amounts of time and effort into the notes, which was reflected in the word count ranging from 452 to 3924 with the average of 1477 words. All the groups used tables, and all, except one, used diagrams and screenshots in their reflection notes.

5.2 Data Analysis

For analyzing the data from the student reflection notes and essays, we use the constant comparative method. The method was originally developed for the use in grounded theory methodology and is now applied more widely for data analysis in

qualitative research. It requires the researcher to take one piece of data and compare it to all other pieces of data that are either similar or different (Glaser 1965).

The data analysis was done after the completion of the course, although the reflection notes were studied by the course staff as they were delivered after each task to make adjustments. The data form each task were analyzed separately. We applied coding to identify the major themes in the student reflections for each practical task, using NVivo software. Later, we triangulated the results with the direct observations done by the course staff and with the outcomes of the tasks. The reflection notes were coded with "priori codes" (Gibbs 2008), such as challenges or achievements in the process for each collaboration mode, categories of boundaries (artifacts, discourses, and processes), discussions on the products/outcomes, and specific tools and technologies used. We were using a technique similar to 'cutting and sorting' (Ryan and Bernard 2003) for identifying the themes, still working separately with the data from each task. In the next stage, we compared the same or similar themes in different tasks (triangulating with other data sources) to identify the key differences between the three collaboration modes used. Finally, we focused the analysis on how the students reflected on different types of boundaries they faced and how they succeeded or failed in overcoming them.

5.3 Study Limitations

The study presented in this paper has a number of limitations. First, we lacked a necessary foundation for the study because of the shortage of prior research on the use of boundary objects in pure educational settings. Therefore, the study is exploratory in nature. Second, we conducted the case study in the presented setup only once and had a small number of participants. This makes it difficult to generalize the results and acquire the same results on a larger group of participants. Third, the participants were skilled software users, which introduced a certain bias, as cooperation technology has been one of the key components of the study. Fourth, we used mostly self-reported data, which could have been biased. Fifth, we could have cultural and language biases as we used English, but participants from at least three non-English speaking countries were involved in the study.

6 Study Results

In this section, we present the result of our study structured by the types of boundary objects used in the course: artifacts, discourses, and processes. We intend that such decomposition of the boundary objects should clarify the collaborative processes we present and their use for collaboration support. For each type, we present how the students used boundary objects provided by the course, created their own objects, and used cooperation technology tools to support these processes. We present how the students reflected on the boundaries they faced in each task and how they succeeded or failed in overcoming them and learning from experience. We exemplify the most common student feedbacks with citations from the reflection notes. These citations

were selected based on their ability to explain certain ideas. The number of citations we selected for this paper per group does not correlate with either word count in the reflection notes or the final grading.

Before going into detail, we will introduce the general results about the use of technologies and knowledge creation outcomes. We will refer to this part when presenting the results related to each boundary object type.

Each student group was using a set of technologies in addition to the ones offered by the course (Fig. 5). These technologies were chosen by the student groups without any specific recommendations from the course staff. These tools performed three major functions corresponding three types of boundary objects. They supported the construction of shared artifacts (e.g., collaborative writing), shared discourses (e.g., communication and reviews), and facilitated cooperation (e.g., group coordination).

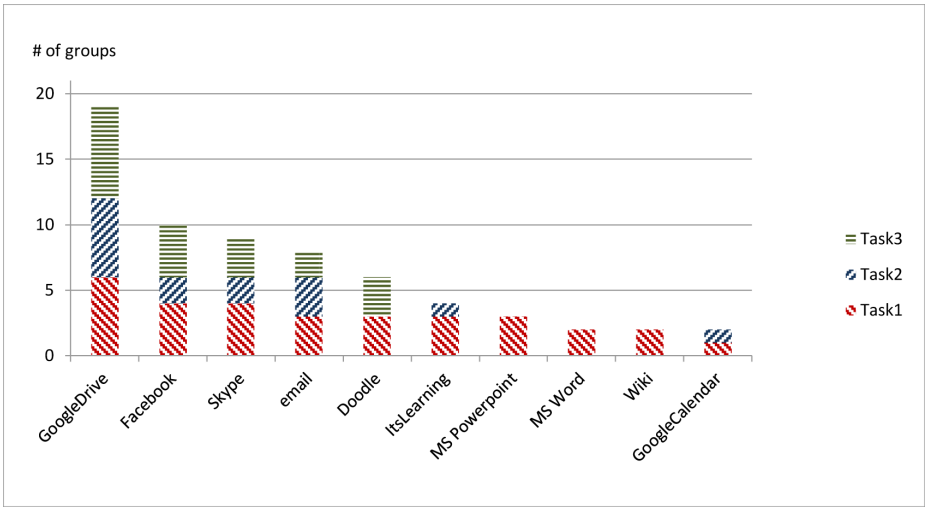

Fig. 5. The number of student groups using specific additional tools in each task

Most of the groups stated that they incorporated familiar tools in their group's technological ecologies. Students stressed that they could start using such tools right away and work more efficiently.

– *[…] instead of striving and possibly spending lots of time to find what might have been the most efficient or most exciting tools for the job at hand, we found it easier to use tools that we were already familiar with (group 4).*

However, students often mentioned that using familiar tools, although contributing to the work done, did not necessarily lead to creative solutions, learning, or change.

– *Our tools were familiar, with […] little overhead and high productivity level. However, for the sake of learning more about cooperation technology, it is possible that we would have benefited from using more unorthodox tools (group 6).*

Two groups explicitly noted that the assigned tools (being unfamiliar, challenging, and different) contributed to the increased understanding of the course topics and facilitated learning.

– *Wikispaces and vAcademia […] most probably required us to think differently than when we use more familiar tools, and although we did not always enjoy using them […], we believe that it taught us even more about how distributed collaboration works (group 4).*

6.1 Boundary Objects: Artifacts

Shared artifacts are tools, documents, models, or virtual places that become boundary objects if they are created by a group or a community and can be understood by all its members (Wenger 2000). Such artifacts have been the central type of boundary objects in this study.

Task 1. Shared artifacts offered/seeded by the course for Task 1 were only the description of the task itself and a template for the expected outcome. Both these objects comply with the definition of an artifact boundary object, i.e. documents and models that are understood by all members of the community (after a round of enquires and updates). The shared artifacts created by the students in Task 1 were the handbooks of tools for cooperation. These artifacts played the role of boundary objects of the artifact type in some of the groups or some members of the groups. The outcomes of the project work were created collaboratively and conveying certain meaning across the boundaries involved in the task, but they were not necessarily completely understood by all members, due to the division of labor in some of the groups.

Similarly, technologies that were directly used for constructing shared artifacts in certain cases played the role as boundary objects of the artifact type. For example, Microsoft Power Point and Word were used only in Task 1 (by three and two groups correspondingly), when the cooperation required less negotiation and equalization of technological preferences (Fig. 5). Another example represents the use of Google Drive/Docs. Six groups were using them, as they were familiar for all the students and more appropriate for collaborative writing (Fig. 5). Therefore, Google Drive/Docs can be seen as a boundary object of the artifact type.

The handbooks were delivered in different formats, five as documents and two as wiki portals (http://tdt4245.wikidot.com/wiki:handbook-for-group-projects/ and http://ctools.wikispaces.com/Collaborative+Tools+for+Designers+Handbook/). According to the task description, the handbook had to include the selection criteria for the presented tools and the intended use. Five groups (not necessarily matching mentioned above) dedicated the handbook to the computer science students or professionals, while the other two – to musicians and to graphical designers.

None of the groups reflected upon any challenges directly related to construction of shared artifacts (as all of them were related to discourses and processes). Starting to work on the virtual presentations of their handbooks, six groups found the vAca-

demia tool too complicated. Nevertheless, all the groups managed to deliver satisfactory presentations (Fig. 2). The virtual recordings of individual groups' presentations became boundary objects, as the students had to rethink their handbooks for the new format.

Task 2. The main shared artifacts offered by the course for Task 2 were the LingoBee app and its repository, which was structured as sub-repositories for each group. The repositories could be accessed through a mobile device or a website and could also be considered as shared artifacts. It should be noted that most of the students were familiar only with their sub-repositories, which made sub-repositories boundary objects for the corresponding groups.

The shared artifacts created by the students in Task 2 were the crowd-sourced Norwegian terms and phrases (Fig. 3a) and the cooperation technology glossaries (Fig. 3b). These outcomes of the project work in this task exemplify the negotiation and creation of a common understanding (especially the entities with several specifying comments), which is a property of boundary objects. Since both these artifacts were created using LingoBee, the artifacts themselves were in the form of LingoBee repositories (the dictionaries are available from http://simola.org/lingobee/index.php?gid=28 and the glossary from http://simola.org/lingobee/index.php?gid=29).

As envisaged, students experienced challenges in using LingoBee for Task 2 and consequently with shared artifacts. The main challenge, as reported by three groups was the lack of familiarity with LingoBee. In addition, all the groups stated that the tool was not fully suited for the Task 2 (b).

– *What confused us with Lingobee was that we did feel that the application and its interface did not match with the requirements for the TASK 2, especially in part b (group 1).*

However, two groups found solutions to overcome the challenges and completed the task using the tool.

– *The usage of the Lingobee tool has shaped the cooperation between the group members in many ways. This tool made monitoring the work progress easier and was good replacement for Google Drive (group 5).*

Three other groups reflected that they found different tools to replace the missing (or undiscovered) functionality, thus resulting in new artifacts. For example, Google Docs were used to create the artifact list of terms for the group to agree upon as LingoBee entries and to discuss the entries within a group as well as the feedback to provide for the other groups' entries. In order to overcome the problems of entering lengthy texts through a mobile device, one group found a solution of using Android emulator, to create LingoBee entries using a desktop computer.

The length and layout limitations for each entry in LingoBee (which was designed to capture language-related contents through text and multimedia) could have prompted synthesis and focus on content rather than layout. However, these limitations have acted as an inhibitor, with students complaining about the limited space and difficulties in formatting.

The two other groups simplified the task to fit it into the basic functions of the tool and partly failed to complete it.

Task 3. The main shared artifacts offered by the course for Task 3 were Purot wiki tool and the outline of the media handbook with abstracts for all seven chapters. In addition, the groups were required to use Prezi for creating presentations of their media chapters. The main shared artifacts created by the students in Task 3 were the chapters of the media handbook (Fig. 4). Similar to Task 2, many students had been working only with their groups' chapters, not the entire handbook with the exception of the peer-review. Therefore, the role of the artifact boundary objects was played by the chapters. The handbook is an open resource available at http://cocreat.purot.net/.

In all the chapters, our students were responsible for the technology-related parts, as indicated in the reflection notes and the interviews. Six chapters were to some degree reflecting the pattern of a pedagogical elaboration of the given challenge enhanced by a set of technological solutions. Five groups conducted literature studies, and three of them supplemented them with field studies. Five groups (not all are the same as above) provided alternative technological solutions. All groups used various media in their chapters. The final presentations made in Prezi were demonstrated live at the joint meeting, using Adobe Connect for connecting universities.

The challenges and opportunities of the shared artifacts in Task 3 varied greatly. Reflecting upon Purot wiki, all the groups found both advantages and limitations. Three groups learnt to use the tool and mitigate its limitations, while four others preferred to use familiar alternative tools and insert polished pieces into Purot wiki. In fact, all the groups used Google Drive/Documents in this task (Fig. 5) either supplementary to Purot wiki or as the main working environment. In both cases, the student groups were constructing shared artifacts and using them across participants with different cultures, expertise, and roles in the joint groups.

6.2 Boundary Objects: Discourses

An important boundary object for this project has been a common language for negotiating meaning across the boundaries. In this case, such a 'language' needed to be established across different study backgrounds, formed group policies, and different cultures. Establishing shared discourses worked very differently in the different tasks and different collaborative settings. The boundaries in international collaboration were especially challenging, but as appears from the student reflection, the experience they gained was the most appreciated.

Task 1. Working on Task 1, students in some of the groups were from the same study program and knew each other well. Six groups out of seven identified their group level collaboration as successful or at least satisfactory. Three groups discussed that the main contributing factors were a good atmosphere, knowing each other beforehand, and having similar motivation levels:

– *The group has worked really good together, and we all had the same goal for this course. We have all put in approximately the same amount of effort (group 3).*

An LMS "It's Learning" was actively used only in Task 1, when the groups' technological environments were not yet fully formed and when the cooperation required less negotiation and equalization of technological preferences. Other groups started using Facebook and Skype for communication and creation of shared discourses (Fig. 5). Face-to-face meetings were also used extensively.

Generally, the students did not reflect on serious problems related to finding a common language within their groups. The only challenges were differences in motivation levels and the necessity to invest time. This was mentioned by two groups:

– *As this was the first task during this course we used some time getting to know each other and finding the collaborative methods that worked for us (group 6).*

Task 2. Establishing shared discourses between the groups imposed more challenges. The students mentioned such challenges 14% more often than benefits in the reflection notes for Task 2, discussing mostly the use of technologies, but also educational and cultural background diversity, lack of shared understanding, and other aspects.

LingoBee is designed to support a shared meaning of an entry through crowd sourcing input from learners and using ideas of social media. For example, it applies ideas of wikis that users could enhance an entry by another user and provide feedback as comments, as enhancements or by rating or flagging entries by other users. Use of these capabilities in LingoBee could be considered as discourse. The LingoBee repositories from the groups show that the students had enhanced and rated each other's entries. Task 2 (b) required that students provide explicit feedback to improve the description and thus the common understanding of the term. In such a way, the feedback provided both within the groups as well as across the groups played the role of a shared discourse, where the meanings of terms were negotiated implicitly.

The students discussed around the terms that they entered to the LingoBee repository, using the chat functionality in Google Drive/Docs and face-to-face meetings. This approach was used for negotiations within a group before passing certain ideas to the cross group level:

– *Before creating the Google document, our group had a meeting where we discussed and commented on the other group's entries before commenting in the shared document (group 4).*

The reflection notes indicate that the students found limitations in supporting cooperation between groups in LingoBee. This may be due to a lack of understanding of the functionalities in LingoBee or it could be due to a preconceived notion of discourse by the students, either through their perceived expectations for the task or habit. We found a strong tendency in cooperation around creating the artifacts and discourse through explicitly coordinated activity such as face-to-face meetings rather than implicit discourse as supported by LingoBee and other tools designed around the principles of crowd sourcing and social media.

Task 3. All the student groups discussed cooperation in Task 3 positively and acknowledged its benefits for creativity and learning. The students emphasized the advantage of working with people with different backgrounds (symmetry of ignorance (Fischer et al. 2007)) for creativity and generally the success of the project, as four groups explicitly stated:

– *We […] were able to complete a far more complicated task than we would have been able to by ourselves. Through working with students with very different expertise than us, we were able to gain insight in to another way of looking at our field of study (group 1).*

The students were encouraged to learn being tolerant to the cultural differences. The fact that the Finnish and Estonians were more "polite" and appreciated "small talk", while Norwegians were more "straight to the point" and "task-focused", led to a gradual adoption of some joint communication norms (or a shared discourse).

Despite the extensive positive feedback, establishing shared discourses became very challenging, and six out of seven groups reflected on that. The students mentioned such challenges 2.4 times more often than benefits in the reflection notes for Task 3. This includes educational and cultural background diversity, lack of shared understanding, and other aspects:

– *Since the teams were from different fields of work, we had different understanding for the same topics so it was sometimes a challenge to explain to each other our points of view and to make a unanimous decision which way to go (group 5).*

Impersonal communication made collaboration on the international level more difficult, as little effort was applied to establish connections and social capital. This was partly addressed by the course staff. Still, it was a serious barrier for the students.

– *We have noticed that […] it is a bit harder to foster both creativity and efficiency with large distributed groups, [as] it takes longer to get to know each other in the starting process. The lack of face-to-face social interaction makes the "getting to know each other" phase more challenging (group 4).*

In many cases, the students failed to establish fruitful communication and create appropriate boundary objects to establish shared understanding, adopting a simplified approach to negotiation of meaning:

– *Having only one person from each country meet online over Skype and then informing the rest locally was quite efficient […]. However it was not helpful when it came to knitting the groups closer together and making the participants feel more connected to the project (group 4).*

Working locally, many groups used face-to-face meetings especially in the beginning of the project work, as a means for social interaction and building trust. Inability to apply this in Task 3 imposed another serious challenge.

– *Although there are tremendous opportunities for both effective and creative work in distributed work, it does demand a bit more effort and time to achieve (group 4).*

All the groups found both advantages and limitations of Adobe Connect – the tool for communication offered by the course. Five groups used it as the main synchronous communication tool (although, only two groups were satisfied), while two

groups switched to more familiar alternative solutions. Purot wiki was the tool for collaborative writing offered by the course for Task 3. Based on wiki technology, this tool also had functionality for creating shared discourses.

6.3 Boundary Objects: Processes

Boundary objects of the process type include negotiated routines and procedures that allow coordination across boundaries, independently by practices established within boundaries (Wenger 2000). Shared processes proved to be an important boundary object type in the presented study. Based on the study data, we can state that creating the processes type of boundary objects was relatively easy within groups. However, it was much more challenging on the cross groups and at the international level.

Task 1. The course did not offer/seed any shared processes for Task 1 and for the processes inside the groups in the other tasks. At the same time, the students created the necessary routines and procedures themselves with relative ease. When reflecting on collaboration within groups, three groups emphasized that the main factors for successful collaboration were planning, coordination, and extensive use of online tools for these purposes:

– *That decision [to use Google Drive, Doodle] enhanced the overall effectiveness of the collaborative effort […] and every active member respected the deadlines (group 5).*

The students did not identify many challenges for establishing shared processes at the group level. Small local groups were easier to coordinate than any activities between local groups or at the international level. The most common challenge was the differences in time schedules of the members. It was discussed by four groups:

– *Collaboration is always a bit tricky when you are in a new group with random people. You don't know each other's working styles, rhythms, motivations, and interests (group 7).*

Task 2. The shared processes provided/seeded for Task 2 were the procedures for posting entities with LingoBee and peer review. The results of the collaboration during this task exemplify the situation when the boundaries were stronger than the boundary objects. When reflecting on collaboration between groups (mostly in Task 2), only two groups discussed how they overcame coordination boundaries between groups. At the same time, five groups reported that the problems were too serious to handle. This meant that the seeded processes did not work as boundary objects, and it became too challenging for most of the groups to create their own.

We identified three major types of challenges with establishing shared processes between groups. The first one was related to negotiating the procedures of giving and receiving feedback between the groups, as two groups explicitly stated:

– *The review of group 4 gave us better insight in how the entries ought to look, as they had done a better job than us with the first draft. Thus, we were now aware of some of the improvements we could do for our final draft (group 1).*

The second type of challenges was related to negotiating how the group would interact with other groups as a single entity (e.g., acting on behalf of the group):

– *Cooperation was a bit more complex than usual. In addition to regular cooperation that exists among team members, there needed to be also cooperation between the teams. That part was a bit challenging because the teams needed to agree on how to give feedback among each other in the best way (group 5).*

Finally, the lack of a leader who would take responsibility for coordinating activities between the groups was explicitly identified by three groups:

– *Coordinating feedback between the groups was hard because there was no natural leader involved. No one wanted to take responsibility for coordinating the groups (group 1).*

The collaborative processes supported by LingoBee were sharing entries with other learners; thus browsing, enhancing each other's entries with new ideas, and providing feedback and ratings. Most of the groups elaborated on the flow of work where a group had an explicit task for individuals to collect their terms, then to discuss them within a group (either via Google Docs or face-to-face), before entering them to the LingoBee repository; i.e. an implicit process of agreeing upon which terms to enter.

The students used conventional means for this process rather than the means of social ranking (such as the star-based ranking or the flagging capabilities in LingoBee). Social ranking could have provided a more complete picture of their individual contributions (e.g., the terms collected by each individual as well as the feedback on each term by individuals) and an insight to their critical evaluation of the terms. The process described in the reflection notes indicate that the artifacts available from the LingoBee repositories are a refined and agreed upon list of terms by the group, outside of the assigned tool. Thus, the creativity that an individual might have in response to a term and spurred by the context in which the user is (e.g., a term that may have been stimulated while walking through the university campus or the city) may have been excluded from this process.

Task 3. A limited amount of shared processes was provided/seeded by the course for Task 3, including online meetings with tutors, expert- and peer-reviews, and the final presentation. When working in joint international groups, the students experienced even more challenges with establishing shared processes, as six groups out of seven explicitly identified. At the same time, all the groups completed the task. The same groups reflected that they valued this experience and that they learnt from it. Collaboration in this task exemplified how the boundaries could trigger reflection and learning.

When attempting to establish shared boundary processes, the students encountered problems that could be roughly divided into three types. The first type of challenges is related to the lack of group cohesiveness:

– *[We] did not get the same feeling of team spirit and group cohesiveness with the internationally distributed group as the local group. Without social interaction in the same way as local teams we did not get the same feeling of responsibility. […] This resulted in less effectiveness and less motivation for the task (group 4).*

The second type is related to negotiating coordination between local groups within international groups. As the students often failed to establish efficient routines for joint meetings, they used "brokers" (Wenger 2000), selected persons from each national subgroup, to negotiate on their behalf:

– *During the project, a clear leader was missed. From Finland and from Norway some people took the responsibility of dividing tasks and making groups but overall a clear feeling of responsibility was missed (group 7).*

Finally, the third type of challenges was related to the lack of appropriate tools supporting cooperation in larger groups. The course did not offer specific tools for creating shared processes, but each group selected them while working on tasks 1 and 2. However, for Task 3, they had to start this process again negotiating with international subgroups, often selecting such tools that were familiar to all subgroups (e.g., Facebook, Skype, and Doodle), and used them more extensively (Fig. 5):

– *Another problem was that there are many tools that can support cooperation between four persons but it is more difficult to find the tool that will have good support of cooperation in larger group (group 5).*

Even though the challenges were quite serious, the students were able to overcome those of the first and the second type, creating their own shared processes.

7 Summary and Implications

In this section, we summarize the results of the study and present our implications for each type of boundary objects. Our analysis shows that boundary objects played an important role in facilitating group work at all levels, but a number of problems were discovered. In particular, when comparing the use of boundary objects in different tasks, we identified the following issues:

Introducing challenges in constructing boundary objects benefits both learning and group work. From the reflective learning perspective, it was justified to give the students challenging and slightly inappropriate tools. This would cause breakdowns that acted as triggers of reflection and learning. The implications for each task are presented below.

The breakdown we designed for Task 1 – giving the students a tool that was too complex, worked well. The results show that all the groups overcame it and most of them reflected on either gaining useful experience or learning. The breakdown for Task 2 – providing a tool with inappropriate functionality worked only for highly motivated groups and degraded the less motivated ones. The breakdown that (partly not intentionally) occurred during Task 3 – limited community support, worked well from the reflective learning perspective, as most of the groups reported positive learning experience. However, this breakdown significantly limited the collaborative knowledge construction process, as the results demonstrate.

Cooperation technology tools playing the role of boundary objects as artifacts, discourses, and processes. The discussion above shows that the breakdowns did not always work as intended, as less motivated students tended to use them as a barrier they did not want to overcome. Therefore, the breakdowns have to be designed carefully. The scaffolding mechanisms that we have put in place to address this risk (e.g., structured reflection notes) were successful only for the most motivated groups. Therefore, better mechanisms are required to scaffold not only the reflection process but also the cooperation process, i.e. tools and mechanisms playing the role of boundary objects as artifacts, discourses, and processes.

The major implications for the use of cooperation technology as boundary objects in course design include the following. First, initial creation of boundary objects as artifacts benefits from a template or a pre-defined structure. Second, boundary objects as discourses are crucial in international, large, and distributed groups, but are challenging to establish. Third, the creation of boundary objects as processes requires direct external support on both the intergroup and international levels.

The tradeoffs. From the social constructivism perspective, providing the students with the most suitable tools and letting them focus on the assignment would have the most positive effect. This means that cooperation breakdowns that we designed following the reflective learning approach reduced this effect to some degree. The results demonstrated that this was the case especially for less motivated students.

We argue that there are tradeoffs between making knowledge construction as smooth as possible and letting students go through multiple experiences, creating triggers to promote reflection. Breakdowns can, to a certain extent, act as such triggers, but there is a risk that they disrupt the construction of knowledge without leading to reflection. If the breakdowns are too difficult to overcome, they may slow down or even stop the process. At the same time, if they are too easy, they may only create unnecessary disruption.

While one of the intentions behind the course was to motivate the students to create own boundary objects, they did not always succeed in that, especially when they did not have anything to start with. However, those student groups who succeeded used the additional boundary objects to facilitate the collaborative process and to learn about collaboration. In this case, the time and effort they invested produced positive results both in terms of reaching the goal and in learning.

As appears from the reflection notes, students expected that certain facilities/boundary objects being already in place such as “established leader” and “shared spaces”. In particular, successful collaboration in diverse a group (as on task 3) requires more complex boundary objects. In addition, the lack of initial boundary objects in such a group may lead to breakdowns in collaboration and limited use of boundary objects in general. While some boundary objects had been provided by the course, they have not always been sufficient. Therefore, we consider our observations and corresponding implications are valuable for course design, especially for structuring collaborative activities.

In the following, we discuss what initial boundary objects should be ‘seeded’ and how to facilitate creation of new ones, especially in a diverse, cross-disciplinary set-

ting. Tables 2–7 summarize the results of the study. In these six tables, we provide the implications first, for seeding and then, for facilitating creation of new boundary objects. These are presented consequently for of all three types of boundary objects – artifacts, discourses, and processes. Each table displays our observations in the first column and corresponding implications and recommendations in the second.

Table 2. Seeding boundary objects as shared artifacts

Observations	Implications and recommendations
Student groups experienced difficulties starting collaboration in tasks 2 and 3. Different preferences in the use of technologies often caused these difficulties.	Create initial shared artifacts to establish a common understanding between sub-groups or individuals (e.g., tutorials, presentations of study topics, templates, and designated tools and repositories).
A single main course environment (LMS) was not used (apart from getting initial tasks and for submissions) as it did not have the necessary functionality.	Establish shared group spaces / tools / artifacts to mediate activities with one major (serving as 'nexus' and the main group space, providing awareness about activities in secondary ones) and several accompanying technological platforms with appropriate means.

Table 3. Facilitating creation of boundary objects as shared artifacts

Observations	Implications and recommendations
Many groups used different tools for working on the same documents (e.g., wiki and Google Docs) and discussed them on other platforms (e.g., Facebook).	Establish mechanisms for linking and annotating versions of boundary objects across different media and support organizing objects in repositories.
Many groups used familiar tools even if the new tool was more effective. This highlights the barriers for investing time in learning new tools.	Provide instructions to make full use of new tools and their potential. Provide a list of alternative tools if possible.

Table 4. Seeding boundary objects as shared discourses

Observations	Implications and recommendations
Materials about the foreign groups were useful, but not sufficient/complete.	Introduce boundary objects in advance, including shared curriculum, study materials, and goal descriptions.
The joint meetings were useful for establishing shared understanding, but the students struggled organizing them.	Conduct scheduled joint activities, including tutorials, workshops, and lectures, especially in the beginning.
Students experienced problems with understanding their collaborators and explaining own point of view across different disciplines.	Establish designated shared information spaces for reference materials.

Table 5. Facilitating creation of boundary objects as shared discourses

Observations	Implications and recommendations
Many students had problems reaching a common understanding of the tasks, roles of sub-groups or individuals. The presence of tutors at the meetings was appreciated.	Provide assistance / moderation during meetings/negotiations.
Many student groups found it problematic to start collaboration without knowing all the peers and their communication habits. Informal communication was acknowledged to be important.	Schedule and conduct ice-breaking and socializing activities in addition to purely course-related collaboration, especially in the beginning.
Communication improved after introducing technologies that were familiar to all the group members (e.g., Google Drive and Facebook).	Provide mechanisms for mapping workspaces and social networks (e.g., connecting user accounts, or shared artifacts, discussions, and data repositories).

Table 6. Seeding boundary objects as shared processes

Observations	Implications and recommendations
Many student groups experienced problems understanding the tasks and their roles, especially when international sub-groups were involved.	Task descriptions should include clear instructions on the process, possible roles for the individuals (or sub-groups), and a timetable.
The more diverse the student groups were, the more problems they had in finding time when all members can meet or work together.	Secure time slots when all participants can be available for joint activities beforehand.
Missing feeling of team spirit and group cohesiveness was reported, especially in international teams.	Organize regular activities in the designated group or course spaces.
Students had problems in finding a suitable tool for supporting collaboration in larger groups.	Provide assistance with complex boundary objects (e.g., groupware tools).

Table 7. Facilitating creation of boundary objects as shared processes

Observations	Implications and recommendations
Some student groups used familiar tools for organizing the collaborative process. However, those who chose learning new tools did not regret.	Provide designated tools that are familiar to the majority of the students to increase efficiency. At the same time, expose students to unknown tools to allow them exploring new collaborative processes.
Individuals (or sub-groups) had different level of motivation, and this caused problems with participation and commitment.	Motivate and assist students in identifying roles. Recommend developing a set of rules/"working contract".
Students had problems identifying a leader, and subsequently had coordination problems.	Provide assistance (e.g., in assigning roles) when no clear leaders available.

In order to perform a systematic analysis of collaborative activities across boundaries, we used a classification framework of boundary objects originally suggested by Wenger for organizational contexts (Wenger 2000). As to our knowledge, this framework has not been used before in educational projects. However, typical student projects exhibit several characteristics of real-life professional projects, which make the framework applicable for educational contexts.

Even though we used the framework for the analysis of collaborative activities, our experience indicates that it provides the breadth necessary to describe and structure most of the collaborative activities in diverse student groups. Therefore, we conclude that the concept of Boundary Objects and the particular framework we applied can be used for facilitating the design of collaborative learning.

8 Conclusions and Future Work

In this work, we have explored how boundary objects facilitate group work and learning across different boundaries in a diverse and cross-disciplinary educational context. We have achieved the objectives of the study. First, we have studied the usefulness of both seeded and created shared artifacts, discourses, and processes in different collaborative and technological settings. We have analyzed when they become boundary objects, as presented in section 6. Second, we have identified learning opportunities provided by the boundaries and suggested how to facilitate cooperative processes within and across groups by seeding appropriate boundary objects and supporting their creation during group work. The analysis is presented in section 6, and the major implications – in the beginning of section 7. Third, we have summarized the results of the study into a set of implications and recommendations for using boundary objects in course design. These are presented in the end of section 7.

We discovered that using boundary objects might improve the design of collaborative learning, especially in cross-disciplinary settings, and therefore suggest pursuing this opportunity as the major direction for future work. There is still a need to explore further the affordances of the concept of boundary objects for supporting and scaffolding educational process. In particular, the characterization of boundary objects we used in this paper presents a certain value and should be studied further.

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