Work and Learning across Boundaries: Artifacts, Discourses, and Processes in a University Course

Mikhail Fominykh[1], Ekaterina Prasolova-Førland[1],
Sobah Abbas Petersen[2], and Monica Divitini[3]

[1] Program for Learning with ICT,
Norwegian University of Science and Technology, Trondheim, Norway
{mikhail.fominykh,ekaterip}@ntnu.no
[2] SINTEF Technology & Society, Trondheim, Norway
sobah.petersen@sintef.no
[3] Department of Computer and Information Science,
Norwegian University of Science and Technology, Trondheim, Norway
divitini@idi.ntnu.no

Abstract. Boundary objects can provide bridges across boundaries and facilitate collaboration between learners 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.

Keywords: cooperation technology, boundary objects, collaborative learning.

1 Introduction

Significant part 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, e.g., 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" [1,2]. On the other hand, cooperation problems among the students are rather common and often lead to frustration and disruptions in the learning process [3,4].

Starting from the core notion of *learning communities*", in this paper we investigate how *boundary objects* can help improving collaboration and learning [5-9] within a university course. In particular, we explore opportunities for collaborative learning that arise when using boundary objects and related challenges.

The paper is based on a Cooperation Technology course at our university that integrates lectures with a group project in which the students had to collaborate in

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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*. Designing the course, we applied the social constructivist approach which implies that learners co-construct their environment and understanding together [10]. 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. Based on this discussion, we outline implications for cooperation support across boundaries in a social learning system, e.g., 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" [5]. They are important to consider for supporting 'social learning systems'[5], 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 subcommunities that join together for some purpose [5-7]. Boundary objects serve groups or communities in situations where each participant has only partial knowledge and partial control over the interpretation of an object [6,8,9]. 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" [6]. Boundary objects are typically negotiated, dynamic and have emergent characteristics.

Boundary objects can take different forms. According to Wenger, boundary objects can be classified into three groups: *artifacts*, *discourses*, and *processes* [5]. *Artifacts* may be documents, models, virtual places [11] that have meaning across boundaries. In our study, shared artifacts can be seen as physical representation 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, and decontextualized. *Discourses* represent a common language that the participants of a collaborative process can use to communicate across boundaries [5]. Discourses are negotiated terms and language constructions that have the same meaning for all the participants. 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 [5], independently by practices established within boundaries. In our case, processes are represented by rules and agreements that allow synchronizing schedules and coordinating work styles of the individual students within and between groups.

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 [5]. When discussing boundary objects in Communities of Interest, Fischer talks about cross-disciplinary designer teams (see, e.g., [12]). The concept of boundary objects is rarely used in pure (not corporate or professional training) educational settings (see, e.g., [13,14]). More work is done on exploring boundaries between institutions and communities (see, e.g., [15,16]). The authors are not aware of any systematic attempts to discuss the matter.

3 Study Settings

Our study is based on the data collected during the Cooperation Technology course at our university in autumn 2012. It was conducted with 31 students working in small groups (seven groups of 3–5 students in each) on a group project (counting for 70% of the final grade). Students had the possibility to form a group themselves, while the remaining students were put together randomly. 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. The project consisted of three tasks. For each task, the students were required to submit reflection notes. In addition, they submitted a final individual essay counted for 30% of the final grading.

Each task was designed to provide experience with a different form of collaboration, investigating three different types of boundaries. To support exploration and learning of different technologies, we designed the tasks around different cooperation technology, plus students could adopt additional tools at their choice for some of the activities, e.g., writing of the reflection notes. The tools we offered in the course were new for most of the students. This was intended to force discussion on the appropriation of technologies, critical thinking and reflective learning [17].

3.1 Task 1: Collaboration and Boundaries within a Group

The first task was centered on collaboration within a group and it gives us the 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. Therefore, in most of the groups, the students had different professional and cultural backgrounds.

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 groups presented their handbooks to their peers and visitors during a virtual seminar (Fig. 1) held in vAcademia 3D virtual world (http://vacademia.com/) and created 3D recordings of their presentations [18]. In such a format, a presentation is a performance and an artifact at the same time.

Fig. 1. Student group presentation in vAcademia

3.2 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 are between the groups which need to understand of each other's work to make a meaningful annotation or build up 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 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. 2).

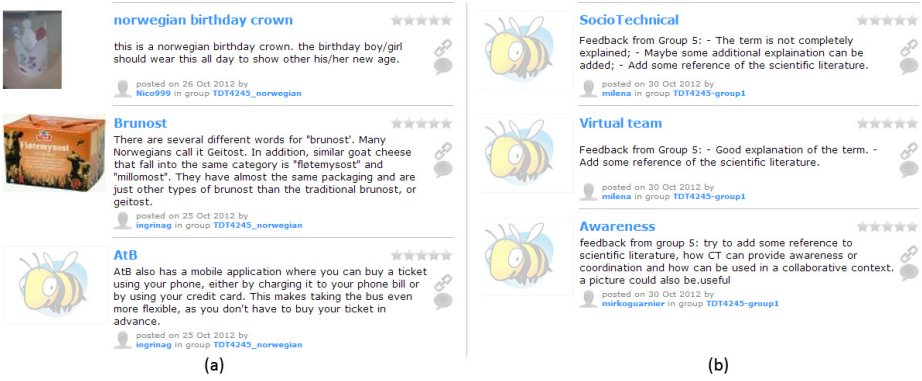

Fig. 2. Boundary Object – artifacts for Task 2 using LingoBee

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 other 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.

3.3 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 need not only understand the work of other entities, but 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 with them.

In order to implement these settings, we designed *Task 3* where the students participated in a joint activity that was designed and conducted by CoCreat project (http://www.cocreat.eu/). This activity lasted five weeks and brought 68 students from Tallinn University (Estonia), University of Oulu (Finland), and our University. Our students were expected to apply their knowledge in a domain (education) that was outside their area of expertise. During the course, larger international groups were formed from local groups. All the course activities were conducted distantly.

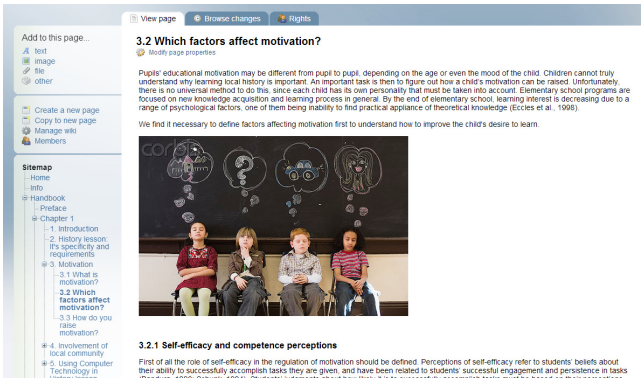

Fig. 3. A screenshot of a media handbook chapter made by the students

The joint activity consisted of several tasks aiming at creating a multimedia book. Each of seven international groups 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. 3). The quality of the resultant handbook chapters was satisfactory. The main misunderstandings of the task were that students from Finland must lead, as their competence was more theoretical. However, the evaluators were satisfied with the results after their comments were addressed.

3.4 Data Sources and Analysis

The data were collected from the direct observation of students' activities online, the virtual artifacts that they produced in each task (including automatically logged data), and users' feedback in the form of questionnaires, group reflection notes, and individual essays. The main data source for this paper was group reflections notes. Following the reflective learning approach [19], we aimed at promoting rethinking of this experience to learn from it. A template was provided for the notes of each task to scaffold the reflection process, pointing out specific issues to consider, e.g., the flow of work during the task and how it was affected by the technology used, how different technology influenced cooperation, and the tradeoff between creativity and efficiency. The notes were written collaboratively in groups, so that the students had to discuss their experience.

For analyzing the data from the student reflection notes and essays, we use the constant comparative method [20] that was originally developed for the use in grounded theory methodology and is now applied more widely as a method of 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. We applied coding to identify the major themes in the student reflections, and later triangulated them with the direct observations of the course staff and with the outcomes of the student projects. Reflection notes for each task were coded separately with some "priori codes" [21] such as challenges and achievements in the process for each collaborative mode, discussions on the products/outcomes, and specific tools and technologies used. We were using a technique close to "cutting and sorting"[22] for identifying the themes.

4 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.

Each student group was using a set of technologies in addition to the ones offered by the course (Fig. 4). 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).

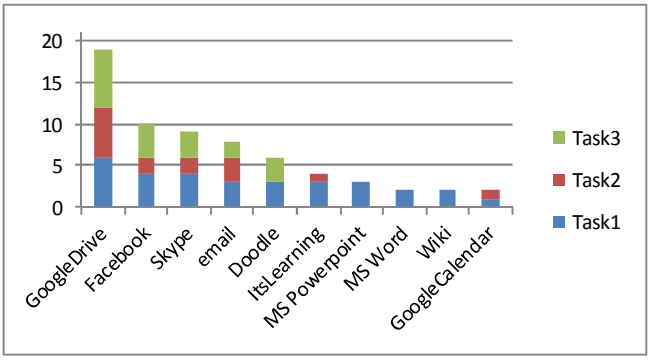

Fig. 4. The number of student groups using specific tools in each task

4.1 Boundary Objects: Artifacts

Shared artifacts have been the central type of boundary objects in this study. In our case, the outcomes of the student group work played the role of boundary objects of the artifact type, being created collaboratively and conveying certain meaning across all types of boundaries involved in the study.

The shared artifacts offered by the course for Task 1 were only the description of the task itself and a template for the expected outcome. The shared artifacts created by the students in Task 1 were the handbooks of tools for cooperation. In addition, technologies that were directly used for constructing shared artifacts can be seen as boundary objects of the artifact type. 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. 4). Six groups used Google Drive/Docs, as was familiar for all the students and the most appropriate for collaborative writing (Fig. 4).

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 task, 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 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 vAcademia tool too complicated. Nevertheless, all the groups managed to deliver satisfactory presentations (Fig. 1). The recordings of single groups' presentations became boundary objects, as the students had to rethink their handbooks for the new format.

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 which can also be considered as shared artifacts. The shared artifacts created by the students in Task 2 were the crowd-sourced Norwegian terms (Fig. 2a) and phrases and the cooperation technology glossaries (Fig. 2b). 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). However, two groups found solutions to overcome the challenges and completed the task using the tool. Three groups reflected that they found different tools to replace the missing (or undiscovered) functionality, thus resulting in new artifacts. The two other groups simplified the task to fit it into the basic functions of the tool and partly failed to complete it.

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. 3). 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. 4) 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.

4.2 Boundary Objects: Discourses

An important boundary object for this project has been a common language for negotiating meaning across the borders. In this case, such a 'language' needed to be established across different study backgrounds, formed group policies, and different cultures. Establishing shared discourses went very differently in 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.

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 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.*

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. 4). 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 significant challenge was the difference in motivation levels. It was mentioned by two 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.*

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; e.g., using ideas of wikis, users can enhance an entry by another user, provide feedback as comments, as enhancements or by rating or flagging entries by others. 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 (see the term "Socio Technical" on Fig. 2b where the entry says that it is feedback from group 5) 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 are 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.*

The reflection notes generally point out the limitations in LingoBee to support cooperation between groups. 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.

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 [2]) 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.*

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 sharing discourses became very challenging, and six out of seven groups reflected on that. The students mentioned such challenges 135% 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.*

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.*

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 is the tool for collaborative writing offered by the course for Task 3. Being based on wiki technology, this tool also had functionality for creating shared discourses.

4.3 Boundary Objects: Processes

Shared processes proved to be 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 international level.

When reflecting on collaboration within groups (mostly in Task 1), 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.*

The students did not identify many challenges for establishing shared processes on the group level. Small local groups were easier to coordinate than any activities between local groups or on 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.*

When reflecting on collaboration between groups (mostly in Task 2), only two groups were discussing how they overcame coordination boundaries between groups. At the same time, five groups were reporting that the problems were too serious to handle. We identified three major types of challenges with establishing share processes between groups. The first one is 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.*

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):

– *Then later that night he had posted his feedback as the entire review, before anybody else had been able to comment. Since we were only allowed to upload one review together as a team, we felt powerless and disappointed.*

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.*

The collaborative processes supported by LingoBee are 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, before entering them to the LingoBee repository; i.e. an implicit process of agreeing upon which terms to enter.

When working in joint international groups in Task 3, the students experienced even more challenges with establishing shared processes, as six groups out of seven explicitly identified. 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.*

The second type in 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" [5], 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.*

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. 4):

– *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.*

5 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 part 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 trends and challenges:

- Successful collaboration in a diverse group requires more complex boundary objects.
- The lack of clear leadership in such a group may lead to breakdowns in collaboration and limited use of boundary objects.
- Initial creation of boundary objects as artifacts will normally benefit from a template or a pre-defined structure.
- Boundary objects as discourses are crucial in international, large, and distributed groups, but challenging to establish.
- Creation of boundary objects as processes requires direct external support on both the intergroup and international levels.
- Cooperation technology tools may play the role of boundary objects as artifacts, discourses, and processes.
- Allowing a certain degree of freedom in constructing boundary objects benefits both learning and group work.

As appears from the reflection notes, students expected that certain facilities/boundary objects being already in place such as "established leader", "shared spaces", etc. Some boundary objects had been provided by the course, but they have not always been sufficient. Also, 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. Therefore, 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 setting.

Table 1. Seeding boundary objects as shared artifacts

Observations	Implications and recommendations
Difficulties in starting collaboration in tasks 2 and 3 (using different tools was a common reason)	Creating 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.	Establishing 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 2. Facilitating creation of boundary objects as shared artifacts

Observations	Implications and recommendations
Use of different tools for working on the same documents (e.g., wiki and Google Docs) and discussing them on other platforms (e.g., Facebook)	Linking and annotating versions of boundary objects across different media, providing mechanisms for organizing objects in repositories
Use of familiar tools even if the new tool was more effective – barriers for investing time in learning new tools	Providing instructions to make full use of its potentials and a list of alternatives

Table 3. Seeding boundary objects as shared discourses

Observations	Implications and recommendations
Materials about the foreign groups were useful, but not sufficient/complete	Introducing 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.	Conducting scheduled joint activities, including, e.g., tutorials, workshops, and lectures, especially in the beginning
Problems with understanding their collaborators and explaining own point of view across different disciplines	Establishing designated shared information spaces for reference materials

Table 4. Facilitating creation of boundary objects as shared discourses

Observations	Implications and recommendations
Problems reaching a common understanding of the tasks, roles of sub-groups or individuals, etc. Students appreciated the presence of tutors at the meetings.	Providing moderator assistance during meetings/negotiations
Problems starting collaboration without knowing all the peers and their communication habits. Informal communication is important.	Conducting scheduled "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).	Providing mechanisms for mapping workspaces and social networks, e.g., connecting user accounts, or shared artifacts, discussions, and data repositories

Table 5. Seeding boundary objects as shared processes

Observations	Implications and recommendations
Problems understanding the task, especially when international sub-groups were involved	Providing task descriptions with clear instructions on the process, including possible roles for the individuals (or sub-groups) and a timetable
Problems in finding time when all members can meet	Securing time slots when all participants can be available for joint activities
Missing feeling of team spirit and group cohesiveness, esp. in international teams	Conducting regular activities in the designated group spaces
Problems finding a suitable tool for supporting collaboration in larger groups	Providing assistance with complex boundary objects (e.g., groupware tools)

Table 6. Facilitating creation of boundary objects as shared processes

Observations	Implications and recommendations
Use familiar tools for organizing the collaborative process (those who chose learning new tools did not regret)	Providing designated tools that are familiar to majority of the students to increase efficiency, and exposing 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.	Motivating and assisting students in identifying roles and developing a set of rules/"working contract"
Problems identifying a leader and subsequent coordination problems	Providing assistance (for, e.g., 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 [5]. 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 makes the framework applicable for educational contexts. We also apply the framework originally developed for communities to student groups since we consider groups as subjects within a learning community and a part of the activity structure as suggested by Engeström [23]. Our experience shows that the framework we used provides the breadth necessary to cover most of the collaborative activities in diverse student groups.

6 Conclusions

In this work, we have explored how boundary objects facilitate group work and learning across different boundaries in educational context. In particular, we have studied how boundary objects are used in different types of group tasks. Based on our experiences, we 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.

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References

1. Fischer, G.: Distances and Diversity: Sources for Social Creativity. In: 5th Conference on Creativity & Cognition, April 12–15, pp. 128–136. ACM, London (2005)
2. Fischer, G., Rohde, M., Wulf, V.: Community-Based Learning: The Core Competency of Residential, Research Based Universities. International Journal for Computer-Supported Collaborative Learning 2(1), 9–40 (2007)
3. Anisetty, P., Young, P.: Collaboration problems in conducting a group project in a software engineering course. Journal of Computing Sciences in Colleges 26(5), 45–52 (2011)
4. Shuangyan, L., Joy, M., Griffiths, N.: Students' Perceptions of the Factors Leading to Unsuccessful Group Collaboration. In: Jemni, M., Kinshuk Sampson, D., Spector, J.M. (eds.) 10th International Conference on Advanced Learning Technologies (ICALT), Sousse, Tunisia, July 5-7, pp. 565–569. IEEE (2010)
5. Wenger, E.: Communities of Practice and Social Learning Systems. Organization 7(2), 225–246 (2000)
6. Fischer, G.: External and shareable artifacts as opportunities for social creativity in communities of interest. In: Gero, J.S., Maher, M.L. (eds.) 5th International Conference on Computational and Cognitive Models of Creative Design, Heron Island, Australia, December 9-13, pp. 67–89. University of Sydney (2001)

7. Star, S., Griesemer, J.: Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. Social Studies of Science 19(3), 387–420 (1989)
8. Arias, E.G., Fischer, G.: Boundary Objects: Their Role in Articulating the Task at Hand and Making Information Relevant to It. In: International Symposium on Interactive & Collaborative Computing (ICC), Wollongong, Australia, December 12-15, pp. 567–574. ICSC Academic Press (2000)
9. Star, S.L.: The Structure of Ill-Structured Solutions: Boundary Objects and Heterogeneous Distributed Problem Solving. In: Distributed Artificial Intelligence, vol. II. Morgan Kaufmann Publishers Inc., San Mateo (1989)
10. Vygotsky, L.S.: Mind in society: the development of higher psychological processes. Harvard University Press, Cambridge (1978)
11. Prasolova-Førland, E.: Virtual spaces as artifacts: implications for the design of educational CVEs. In: International Conference on Cyberworlds, Singapore, December 3-5, pp. 396–403 (2003)
12. Fischer, G., Ostwald, J.: Knowledge Communication in Design Communities: And How They May Be Overcome. In: Bromme, R., Hesse, F., Spada, H. (eds.) Barriers and Biases in Computer-Mediated Knowledge Communication. Computer-Supported Collaborative Learning Series, vol. 5, pp. 213–242. Springer (2005)
13. Huang, E.Y., Huang, T.K.: Measuring Boundary Objects in an Attempt to Explain Innovativeness. In: Ralph, H., Sprague, J. (eds.) 46th Hawaii International Conference on System Sciences (HICSS), Wailea, HI, USA, January 7-10, pp. 3645–3653. IEEE (2013)
14. Beddall-Hill, N.L., Jonathan, R.: Mobile Devices as 'Boundary Objects' on Field Trips. Journal of the Research Center for Educational Technology 6(1), 28–46 (2010)
15. Nolen, S.B., Horn, I.S., Ward, C.J., Childers, S.A.: Novice Teacher Learning and Motivation Across Contexts: Assessment Tools as Boundary Objects. Cognition and Instruction 29(1), 88–122 (2011)
16. Jansen, A., Herbel-Eisenmann, B., Smith, J.P.: Detecting Students' Experiences of Discontinuities Between Middle School and High School Mathematics Programs: Learning During Boundary Crossing. Mathematical Thinking and Learning 14(4), 285–309 (2012)
17. Boud, D., Cressey, P., Docherty, P.: Productive reflection at work: learning for changing organizations. Routledge, London (2006)
18. Morozov, M., Gerasimov, A., Fominykh, M.: vAcademia – Educational Virtual World with 3D Recording. In: Kuijper, A., Sourin, A. (eds.) 12th International Conference on Cyberworlds (CW), Darmstadt, Germany, September 25-27, pp. 199–206. IEEE (2012)
19. Boud, D., Keogh, R., Walker, D.: Reflection: Turning Experience into Learning. Kogan Page, London (1985)
20. Glaser, B.G.: The Constant Comparative Method of Qualitative Analysis. Social Problems 12(4), 436–445 (1965)
21. Gibbs, G.R.: Analysing Qualitative Data. SAGE Publications, London (2008)
22. Ryan, G.W., Bernard, H.R.: Techniques to Identify Themes. Field Methods 15(1), 85–109 (2003)
23. Engeström, Y.: Learning by expanding: An activity-theoretical approach to developmental research. Orienta-Konsultit Oy, Helsinki (1987)