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Contrasting analytical approaches to trace collaborative learning with knowledge objects

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Abstract: Social, discursive and regulatory aspects of collaborative learning have been examined extensively. Yet, there is less research and systematic analysis on how the collaboratively constructed knowledge objects introduce and structure the conditions for collaborative processes and learning. In this symposium, we share and contrast methods and approaches to analyzing collaboration activities that involve digital knowledge objects being developed jointly (i.e., essays, posts in online discussions, versions of a product) in four different educational contexts in tertiary education. The four contributions, from Netherlands, Australia, Norway and Finland present a range of analytical approaches, collaboration analytics and qualitative interpretations of collaborative learning with knowledge objects. The contributions are part of an overarching effort to develop analytics-based approaches, frameworks and instruments that allow to systematically capture the complexities of the collaborative process, for further use in research and for supporting educational practice.

General Introduction

Collaborative, small group activities are strategies that provide learners with the opportunities to work with knowledge contents and advance collaborative competence through discussions, negotiation, writing or creating together, and managing joint work. Often, such collaborative work involves activities with knowledge objects. These can be artefacts such as shared workspaces or tools within a group's collaborative environment, e.g., representational tools or visualizations, but can also be groups' shared products (e.g., students' assignments, reports, data). Social, discursive and regulatory aspects of collaborative learning have been examined extensively (e.g., Järvelä et al., 2019; Trausan-Matu & Slotta, 2021; Wise & Chiu, 2011). Similarly, the knowledge building theory and empirical research offers a principle-based pedagogy of how ideas, treated as conceptual artifacts, are subject to continual refinement in a knowledge building community (Scardamalia & Bereiter, 2006). However, there is a need for further research on collaborative processes that particularly focus on digital knowledge objects as developing entities open for negotiation, revisions, and co-creation. In this symposium, we share methods and approaches to analyzing collaboration activities that involve digital objects being developed jointly (i.e., essays, posts in online discussions, versions of a product, digital format presentations) in four different educational contexts in tertiary education. The four contributions present a range of analytical approaches, including mixed methods analysis, analytics of online collaboration and qualitative interpretations of small-group activities and collaboration on knowledge objects. The contributions are part of an overarching effort to develop analytical, technology-enhanced approaches, frameworks and instruments that allow us to capture, in a systematic way, the complexities of the collaborative process, for further use in research and for supporting educational practice.

The integrative point of this symposium is an analytical elaboration of central processes in collaboration and particularly those linking collective efforts around knowledge objects, artefacts and the processes of improving these outcomes. Hence, the significance of the symposium contributions is centrally related to an internationally shared analytical agenda addressing antecedents, processes, and consequences of collaboration with knowledge objects. The first symposium presentation introduces these concepts and, further, focuses on the process with an analysis of group size and regulation. The second presentation introduces innovative computational approaches to automatically analyze key terms and linguistic complexity of discussion posts, to unveil how these characteristics affect the volume of subsequent exchange and course performance. The third presentation presents how knowledge objects are co-created by student groups through collaborative

programming and three sensitizing notions for interpreting (emergence, object function, assemblage) the nature of these object-oriented processes. The fourth presentation investigates the position the shared objects take in collaboration and how competence in collaboration around digital knowledge objects was displayed. Taken together, the presentations advance integrated conceptualizations and methods for analyzing CSCL in future research designs.

The symposium engages the audience to contribute through online questions and commenting (in a selected digital tool) as well as live discussions during the symposium. The presentations will each contribute a position and empirical evidence on one or several of the following questions for the audience. 1. Analytical perspectives: What is required of analytical methods to trace collaborative learning around digital knowledge objects? What is omitted if the focus is solely on digitally traceable collaboration? What should the future (automated analysis) solutions include to overcome this gap? 2. Outcomes of collaboration: What are learning designs that invite students to collaboratively engage ideas, strategies and challenges? How does the focus on knowledge objects in collaboration change the expectations about outcomes of collaboration? How to become explicit about the antecedents, processes, and consequences of collaboration with knowledge objects?

Understanding digital traces of collaborative learning with knowledge objects: Investigating antecedents, processes, and consequences of collaboration

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Introduction and aims

Knowledge objects (i.e., students' assignments, essays, reports) play an important role during collaborative learning: they evolve as representations of students' collective or individual knowledge and thus provide a window on students' understanding. Furthermore, knowledge objects can serve as resources for conversation during collaboration (Suthers et al., 2003). Research on collaborative learning can often be characterized as either effect-oriented research (e.g., Does requiring students to produce a knowledge object affect student achievement or understanding?) or process-oriented research (e.g., How can group members' interaction while collaborating on a knowledge object be characterized?). We argue that to gain an understanding of collaborative learning with knowledge objects it is necessary to study – simultaneously – the antecedents, processes, and consequences of collaboration with knowledge objects (cf. Janssen et al., 2010; Janssen & Kirschner, 2020; Stodolsky, 1986). The *antecedents* of collaboration refer to student-, group-, task-, or technological characteristics that affect the way students collaborate. The *processes* of collaboration refer to descriptions and qualities of the interactions between group members when they collaborate. Finally, the *consequences* of collaboration refer to resulting effects of the antecedents and processes of collaboration (e.g., individual achievement, group performance, perceived efficacy).

The aim of this contribution is to illustrate how studying the antecedents, processes, and consequences may further our understanding of collaboration with knowledge artifacts, in comparison to studying one of these aspects in isolation. Using data from university students' online collaboration, we will highlight qualitative and quantitative approaches to analyze (a) how group size (antecedent) affects students' online discussion (process), and their written texts (consequence and knowledge object), and (b) how students reference and involve their written texts during the (social) regulation of their collaborative process (process) and how this affects the quality of their written texts (consequence). We will discuss opportunities and challenges of these kinds of analyses.

Research questions:

(1) What is the relation between group size (dyads versus quartets) and students' discussions during CSCL?

(2) What role do knowledge objects play during groups' regulation of the collaborative process?

(3) How does regulation of the collaborative process relate to the quality of the collaboration outcome?

The sample consisted of 155 students in Higher Education, of which 115 were female. The range in age was 20 to 52 years (M= 26.7, SD= 6.5). The study included individual and collaborative elements. For the collaborative elements, students were randomly assigned to a dyad or quartet, resulting in 16 quartets and 41 dyads. Due to some students' absence, there were also 3 triplets, which were removed from the data and not taken into account in the analyses.

Table 1 displays the general procedure of the data collection. After signing informed consent, students filled in questionnaires concerning demographics and a number of background variables (which will not be included in the analyses), as well as a pretest. Students then read information about genetically modified food (GMF), either disadvantages or advantages. After reading, students started the collaborative assignment, which was to discuss whether or not GMF is a good idea. Students were divided into dyads and quartets. All groups had

to write a short essay with arguments for their opinion. In each group, there was an equal number of students that read about advantages and disadvantages of GMF. Students collaborated via a CSCL environment (*Etherpad*), including a chat-tool and a shared text editor. After the assignment, students filled in questionnaires about their experiences during the assignment (these questionnaires are not included in the analyses) and a posttest.

Table 1
Outline of data collection

Informed consent	Questionnaires	Pretest	Reading individual information	Collaborative assignment (*In dyads or quartets)*	Questionnaires	Post-test
10 min	10 min	5 min	10 min	45 min	10 min	5 min

In the analyses, we will focus on the difference between the dyads and quartets and the role of the collaborative object by examining the chat conversations and the quality of the written essays. The findings of the study will help illustrate how studying the antecedents, processes, and consequences may further our understanding of collaboration with knowledge artefacts, in comparison to studying one of these aspects in isolation.

Automatic text analysis of collaborative knowledge construction

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Educators widely utilize collaborative discussion tasks in digital learning environments. In these tasks, students are often afforded the opportunity to more deeply engage with course content and construct new knowledge of a domain, while exchanging discussion posts with their peers (Hew & Cheung, 2011; Lan et al., 2012). Students thus select, synthesize and reflect upon information they learned during the course, and share this new knowledge in an online discussion board with their peers (Han & Ellis, 2019; Tsai & Tsai, 2013).

In this context, the discussion post contributes to the quality of the overall online discussion and understanding that students collaboratively create. For this reason, discussion posts are critical to advance a collective knowledge object in online discussions. To create quality discussion posts, students need to properly integrate (often isolated) parts of course information and clearly communicate this new knowledge to their peers, initiating a productive topic-oriented exchange (Raković et al., 2020) that, in turn, boosts learning achievements in the course (Zheng & Warschauer, 2015). Students thus need to engage in high levels of knowledge construction while composing their posts to fully benefit from these tasks. This, however, remains a challenge to many students (Holland, 2019).

Researchers have documented that the analysis of linguistic characteristics of discussion posts can reveal 1) what parts of course content are embedded into the post, 2) how these parts of knowledge are bound together in the post, and 3) how clearly this new knowledge is conveyed to peers (e.g., Fu et al., 2016; Huang et al., 2019). The results from these analyses promise to inform future instructional interventions to help students engage in more productive knowledge construction in online discussions.

Adding to this line of research, our contribution explores the viability of using innovative computational approaches to automatically analyzing key terms and linguistic complexity of discussion posts and to unveiling how these characteristics affect the volume of subsequent exchange (i.e., number of replies a post receives) and course performance (i.e., exam scores). We analyzed a substantial sample of online discussion posts created by the university students. Specifically, we aimed at answering the following research questions: 1. To what extent the number of glossary terms in a post and linguistic complexity of a post can predict the number of replies a post received? 2. To what extent the number of glossary terms in a post and linguistic complexity of a post can predict the student performance on the exam?

We analyzed online discussion posts of 81 students enrolled in the epidemiology course at a large Australian university. The students were aspiring public health practitioners. The discussion assignment lasted for 5 weeks and one specific course topic was discussed every week. In each week, the students were required to create one original post and respond to the posts of two other peers. In the original post, students were prompted to reflect on topic knowledge that was new to them during that week and reflect on how this new knowledge helped them improve their skills as public health practitioners. In these discussions, the students could also reflect

on the way they planned, researched and developed an argumentative essay, a major assignment in this course, administered in parallel to the online discussion assignment.

The students created a total of 1,787 posts with a mean length of 342 words (SD=260). Of these, the words "essay", "paper" or "assignment" (including their morphological variants) were found in 81 post students mentioned. We excluded these posts from the dataset prior to analysis and focused our analysis on the posts in which students reflected on a newly constructed topic knowledge (and not on the essay assignment).

Data preparation will include the following steps:

Linguistic complexity of an original post. We will compute the linguistic complexity of an original post for each student. To this end, we will use the Coh-Metrics tool (Graesser et al., 2004) to calculate lexical diversity (i.e., number of unique words), average number of rhetorical connectives and average sentence complexity of a post. For each post, these three indices will be added together. This value will be averaged across all the posts, per student.

- *Linguistic complexity of an original post.* We will compute the linguistic complexity of an original post for each student. To this end, we will use the Coh-Metrics tool (Graesser et al., 2004) to calculate lexical diversity (i.e., number of unique words), average number of rhetorical connectives and average sentence complexity of a post. For each post, these three indices will be added together. This value will be averaged across all the posts, per student.
- *Linguistic complexity of a reply post*. We will compute the linguistic complexity of a reply post for each student following the same procedure as for original posts above.
- *Mean number of glossary terms*. We will also compute the average number of course specific terms provided in each post, per student. The terms will be listed in the course textbook glossary.
- *Mean number of replies*. We will obtain the average number of replies each student received.
- Exam achievement. We will obtain scores students received on the exam that tested their knowledge of the discussed topics.

To answer RQ1, we will conduct the regression analysis to investigate to what extent the mean linguistic complexity of original posts and the number of glossary terms in a post predicts the number of replies that a student received. Similarly, to answer RQ2, we will conduct the regression analysis to investigate to what extent the mean linguistic complexity of original and reply posts and the mean number of glossary terms in a post predicts student performance on the exam.

Our findings can provide support to or challenge existing theoretical assumptions about knowledge construction in collaborative learning tasks (e.g., cf. Weinberger & Fischer, 2006). Moreover, our findings can inform the development of innovative computational approaches to monitoring the quality of student posts and timely identifying students who need support to improve the quality of knowledge construction and conveyance in online discussions.

Assemblage, emergence and objects - empirically sensitive concepts in qualitative analysis of undergraduate collaborative learning

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This study presents a qualitative analytical approach applied to Software Engineering undergraduate students' collaborative development of software. To arrive to generate software solutions, students must learn how to make sense of and engage with programming and programming resources. Our study examines how students use programming strategies and collaborate to co-construct a shared knowledge object, i.e., the code/software. It presents and discusses an analytical approach applied to processes of learning through collaboration and co-creation of shared knowledge objects in an undergraduate software engineering program.

Research has shown that learning situations should offer students the opportunity to address open and complex problems, collaborate and interact to generate new meaning and knowledge that involves sophisticated solutions and knowledge objects (e.g., Damsa & Ludvigsen, 2016; Muukkonen et al., 2010). Fewer studies, however, attempted to elucidate the empirical conditions under which the products of collaboration—knowledge objects in this particular case—emerge from these processes and how these objects impact further learning. Reasons for these limited insights could be that such processes are complex and require specific analytical effort. The current study aims to provide a better understanding of: a) how knowledge objects are co-created by student groups through collaborative programming; and b) what analytical approaches (or strategies) have potential to unveil the nature of these object-oriented processes.

Knowledge objects (or artifacts) are a prominent feature of the programming field. In this context, for students, the challenges emerge to construct a solid understanding of the domain-specific knowledge often through work aimed at creating concrete digital objects, such as software programs, games, applications, websites, etc. Knowledge objects are developing entities and can be addressed in collaborative settings by negotiating, drafting, developing and materializing new ideas and solutions. Rheinberger (1997) distinguishes technological object/objects as instruments, i.e., clearly defined and finished objects with an instrumental role, from the epistemic or knowledge objects, which are question-generating, open to transformation, and have the potential to open new lines of inquiry. For the analytical purpose of this study, it is exactly this dual potential of the knowledge objects, which can allot the object the role of mediating tool or object of inquiry: either as an amalgam of material and conceptual (ideatic) *resources*, which activate a set of opportunities when they are employed (Markauskaite & Goodyear, 2017), or as knowledge objects, which makes them more *processes and projections* rather than definitive things.

As part of a larger research project examining quality of teaching and learning in higher education, this study was conducted in a Software Engineering bachelor's degree program in the engineering and information technology at a university of applied sciences. Two first-year courses were included, one on Web Design and Development (A) and Software Development (B). This study capitalizes on the intensive follow-up of sixteen students/4 groups (2 female, 14 male) in one course and fifteen students/4 groups (all male) in the second. The courses contained varied learning and instructional strategies: lectures, bi-weekly lab sessions, group tutorials; and a collaborative *development project* that required student groups to develop, in course A, a functional webpage and in course B, a digital board game.

We collected a rich set of data: interaction data (video recordings of group meetings, online communication), knowledge objects (notes, mock-ups, versions of the products), course materials and resources the groups used. The micro-level qualitative analysis involved a thematic mapping of interactional data and objects/resources groups used. The analytical strategy opened up for the inclusion of what is emergent, new and unexpected in the examined collaborative processes. In the first phase of the analytic process, we repeatedly viewed/read transcripts of the interaction data, indexed topics, and annotated (verbal) activities. This was aimed at identifying emerging themes that might require further scrutiny (Braun & Clarke, 2006); it also resulted in a mapping of the objects/resources used by the groups. In a 2nd second phase, we employed an interpretative approach and three sensitizing notions for interpretation: emergence - for how meaning is created when bringing ideas, knowledge from sources and concrete actions (e.g., gestures, writing/coding) together; object function - emerging activities that accounted for how developing objects were dealt with; and assemblage - gathering and organizing heterogeneous relations and knowledge resources.

The student groups worked through their collaborative programming task by employing structured set of steps, individual coding and frequent discussions of coding strategies, and an iterative trial-and-error strategy. The group discussions frequently raised new issues and questions, which contributed to advancing both the inquiry and the knowledge product groups were working on. The collaborative development work was supported by easily accessible coding strategies and guidelines, procedural structures, validation standards and tools, shared or derived from professional collections of resources. The students identified the resources, but in order to assemble a set of relevant knowledge and actions they first had to 'decode' the historically developed, encoded knowledge, then meanings could be contextualized and adapted to the specific task. Programming could then take place, and through that, new sense was created through the knowledge product. We frame the entire process as a sequence of necessary actions consisting of: assembling resources – unpacking their meaning – adapting the knowledge to the task purpose – generating knowledge. But these findings also indicate that the challenges lie, for students, in engaging in a meaningful manner with these procedures and knowledge of programming, instead of simply using ready-made procedures (as technical objects) and without trying to understand their underlying logics.

The study's findings emphasize the necessity for students to collaboratively engage ideas, strategies and challenges when pursuing programming solutions. Collective trialing of developing code enabled groups focusing the discussion and the developing efforts, productive both for learning and for engaging challenges. The analytical approach employed allowed gaining in-depth insights into both collaborative actions aimed to advance the shared object and to address challenges. The role and the value of the shared object can be identified and qualified through a double-step analysis, and the use of a data-driven but theory- informed analysis. The study also yields implications for education programs that attempt to employ knowledge co-creation elements in the learning activities. From a general research perspective, this study opens up further lines for investigation and analysis that can provide deeper insights into strategies that enable students to participate meaningfully and become competent in constructing knowledge objects.

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Qualities of shared objects, collaboration processes, and related competence gains

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A key feature in present work-life is constant change. To manage and anticipate this change, knowledge workers need to respond to the growing complexity and dynamic nature of tasks (Benoliel & Somech, 2015) and constitute practices for renewal of knowledge, establish best practices and acquire collaboration competence (Fenwick, Nerland, & Jensen, 2014). How students in tertiary education are directed to engage in such activities is instrumental for competence development (Goodyear & Dimitriadis, 2013; Damsa & Muukkonen, 2020). However, the relationship of students' collaboration around digital epistemic knowledge objects and related competence gains remains not well understood.

Prior research in both educational and professional contexts has examined the articulation of mediating conceptual and tangible artefacts (Miettinen & Paavola, 2018). Such shared knowledge objects are at the core, for instance, in new product development, the production of research articles, or new guidelines for procedures. Students should learn how various tools, artefacts, and conceptual and practical knowledge are manipulated in knowledge work processes. How students experience such collaboration tasks framed by shared digital knowledge objects and related competence learning needs to be investigated further.

This study investigates two courses in higher education to describe the position the knowledge objects took in collaboration and how students describe the process and outcomes. The following research questions were addressed: 1. What kinds of benefits and problems the students described related to collaboration on knowledge objects? 2. How did the students self-evaluate their knowledge work competence learning? 3. How did the group-level learning outcomes relate to students' self-evaluated competence learning?

Case A, a master's degree level course involved collaboration in groups by means of writing a group essay as an outcome and teaching the content to the other students through holding a presentation of their group essay. Case B, a course for first year bachelor students in educational sciences (including various degree programs). Both courses (5 ECTS) involved seven teacher lead lectures and a collaboration outcome, group or dyad essay.

This study employs a multiple case study design (Yin, 2013) with both qualitative and quantitative methods. Students answered the Collaborative Knowledge Practices (CKP) questionnaire (Muukkonen et al., 2020; Karlgren et al. 2020), including 7 scales (27 items) and three open questions, about their learning of collaborative knowledge practices and course experiences. In all, 95 students participated (female N=82, male N=13, mean age 26, Case A students were on average 4.9 years older).

Answers to open-ended questions were analyzed using thematic content analysis (Braun & Clarke, 2006). Statistical analyses compared student mean scores on the seven CKP questionnaire scales and their relation to the group-level course grades. A t-test compared mean scores and effect sizes (Cohen's d) of CKP scales.

The duration of collaboration and the role of the knowledge object were different. In Case A, the object largely structured the collaboration: students (3-4 person groups) were guided to pose a research question to guide their inquiry, to carry out a literature search and use their shared expertise to construct research-based explanations to their (revised) questions. In Case B, the dyads were instructed to take a real-world challenging example (e.g., a behavioral or learning problem in educational context) and use concepts and research from the course literature to explicate it. The object had more the role of facilitating investment in reading the literature and identifying theory-practice relations with a peer.

To understand how students experienced the collaboration on shared objects, positive and problematic aspects were analyzed in the open-ended answers. In Case A, the most frequently described positive aspects were: Expertise through learning content and its application, Collaboration atmosphere, Collaboration and reflection, Type of course work and teaching, and Scientific co-authoring. In Case B, these were Type of course work and teaching and Expertise through learning content and its application. Aspects of collaboration received few mentions. In Case A, students most often mentioned as problematic: Combining interests and delineating objectives, Scheduling, and Collaboration coordination. In Case B, these were Getting overview of content learning, Scheduling, and Type of course work and unclear expectations.

Students in the two cases reported significantly different learning on four scales of the CKP: Collaborate on objects, Integrate efforts, Feedback, and Persistent development, with Case A inquiry course generating higher learning (see Table 2). Analysis of the relationship of grades and self-reported learning is in progress.

On the exterior the two courses held many similarities in type of course work and collaboration activities around the knowledge object. In the course carried out as a longer-term inquiry process, Case A, the students reported more positive experiences related to collaboration atmosphere, the reflection of collaboration, and

scientific co-authoring. In addition, they reported significantly higher learning on integrated efforts in collaboration, learning of feedback practices, and persistent development of shared objects. The students in Case B, the lecture course with a less engaging knowledge object and shorter collaboration, reported more about the type of course work and learning content expertise as positive aspects.

Table 2
Self-assessed competence development on the Collaborative Knowledge Practices scales

Scale	Scale alpha	Case A: Inquiry		Case B: Lecture			
		M	SD	M	SD	T [93]	Cohen's d
Collaborate on objects	.78	4.04	.55	3.69	.63	2.846*	.59
Integrate efforts	.76	4.03	.66	3.56	.54	3.801***	.78
Feedback	.86	3.80	.65	2.71	.78	7.391 ***	1.52
Persistent development	.74	3.82	.46	3.11	.59	6.544 ***	1.34
Various disciplines	.63	2.86	.67	2.79	.68	.536	.10
Interdisciplinary collaboration	.75	2.43	.95	2.12	.77	1.757	.36
Exploit technology	.82	2.87	.89	2.93	.71	-.407	.07

*$p < .05$; ***$p < .001$, M = Mean, SD = Standard deviation.

Particularly interesting in terms of competence development were those aspects described as problematic. The Case A students described the challenge of combining collaborators' interests and delineating the objectives for the group essay. These require intensive negotiation and coordination effort both in the epistemological and regulatory sense to ensure coherence of the knowledge object. Scheduling was emphasized, which is a typical challenge in collaboration. Students were at different stages of their studies, which is a limitation that could influence self-evaluations of competence learning. However, the comparison suggested that prolonged activities and designed feedback practices promoted competence in collaboration around knowledge objects. This can guide the design of analytics-based approaches with embedded scaffolds for collaboration.

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