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Learning relations of knowledge transfer (KT) and knowledge integration (KI) of doctoral students during online interdisciplinary training: an exploratory study

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Abstract

Interdisciplinary training for doctoral students is an emerging scenario in higher education. The learning relations of knowledge transfer (KT: transferring knowledge from one person to another) and knowledge integration (KI: integrating or synthesizing perspectives from different disciplines) built by doctoral students play an important role in the process of interdisciplinary training. This study explores how doctoral students from a wide range of disciplines build learning relations of KT and KI during online interdisciplinary training. A mixed-methods approach was applied. First, longitudinal social network analysis (SNA) was employed to investigate the patterns of KT and KI relations over a seven-month training period. Subsequently, interviews were conducted to triangulate the SNA findings. SNA results show that the establishment of KI relations is significantly less than that of KT. Qualitative results show three themes explaining the challenges of KI relations, including challenges of online settings, the design of the training modules, and student involvement. Practical implications are drawn for the improvement of online interdisciplinary training, such as suggestions to promote KI and strategies for group learning.

Keywords: interdisciplinary education; doctoral education; knowledge transfer; knowledge integration; social network analysis

Introduction

Interdisciplinarity, broadly defined as interactions between different bodies of knowledge, is claimed as essential in addressing complex problems our society faces (Huutoniemi, Klein, Bruun, & Hukkinen, 2010; National Science Foundation [NSF], 2011). Over the past years, a continuing emphasis is placed on interdisciplinary research, and interdisciplinary doctoral programmes in higher education in particular (Vanstone et al., 2013). In these programmes, doctoral students are provided with informal and formal interdisciplinary learning opportunities such as networking in

interdisciplinary consortia, engaging with other disciplines, collaborating in interdisciplinary academic activities (grant applying, teaching, researching, publishing, etc.), and receiving interdisciplinary training. Interdisciplinary training indicates that participants from different disciplines learn about different disciplinary perspectives in order to advance capacities to address problems that extend the scope beyond a single discipline (Rhoten, Mansilla, Chun, & Klein, 2006). Yet, for departments and faculties, providing interdisciplinary training is not a trivial undertaking due to pedagogical and organizational challenges (Lyall, Meagher, Bandola, & Kettle, 2015). Interdisciplinary training has been studied from the perspectives of the institutional process, learning outcomes, educational activities, and student experience (Hannon, Hocking, Legge, & Lugg, 2018; Lindvig, 2018; Lindvig, Lyall, & Meagher, 2017). The interdisciplinary learning process is a critical aspect of interdisciplinary training for doctoral students. However, little is known about this process in which participants learn from different disciplinary perspectives (Gardner, Jansujwicz, Hutchins, Cline, & Levesque, 2014).

The theory of social constructivism, which underpins interdisciplinary education (Hean, Craddock, & O'Halloran, 2009), poses that the doctoral students' interactions with peers and instructors are very important for their knowledge construction during the interdisciplinary learning process (Adams, 2006). One way to study student interactions is to investigate learning relations. A learning relation is a type of interaction and/or connection between participants to obtain interdisciplinary knowledge, for example, seeking advice, providing feedback, acquiring knowledge (Haythornthwaite, 2008). A number of studies investigated learning relations such as 'working with', 'learning from', 'responding to inquiries, and 'joint problem-solving' to understand and improve the learning process (Cela, Sicilia, & Sánchez, 2015; Rienties & Heliot, 2018).

The literature suggests that knowledge transfer (KT) and knowledge integration (KI) are two important learning relations in an interdisciplinary context (Haythornthwaite, 2006; Klein, 2011; Rhoten, 2003). KT refers to transferring knowledge from one person to another. A KT relation develops when person A acquires knowledge from person B. KT is a primary requirement in interdisciplinary training. It enables students to develop a set of multiple disciplinary insights, which is the foundation of interdisciplinary collaboration (Mansilla, Duraisingh, Wolfe, & Haynes, 2009). KI at the other hand refers to an integration or synthesis of perspectives or insights (concepts, techniques, data, etc.) from different disciplines. A KI relation develops when person A discusses integration ideas with person B, such as a method or a research plan that integrates two or more disciplines. KI is claimed as a defining characteristic of interdisciplinary research and collaboration (Klein, 2011). Once the integration of disciplinary perspectives is achieved, scholars can produce an interdisciplinary understanding of a complex problem (Pennington, 2016). To evaluate interdisciplinary research, an indication of the degree of KI needs to be involved (Wagner et al., 2011). It is worth mentioning that the KT and KI relations in this study meant to find out how doctoral students interact or connect to each other, and how the construction of knowledge happens between the students. The KT and KI relations do not indicate the outcomes of knowledge transfer and integration such as skills development, behaviour changes, and interdisciplinary citations and co-authoring in publications (Porter & Rafols, 2009; Wagner et al., 2011).

At present, there is a paucity of research on whether and how doctoral students build KT and KI relations with peers and instructors during interdisciplinary training. We conducted this exploratory study to understand how the learning relations of KT and KI were developed over time by doctoral students. Furthermore, this study was

conducted in an online interdisciplinary training setting, meeting the needs of improving online interdisciplinary training in inter-institutional and international projects.

Complexity of KI

When working together over a sustained period of time, participants in interdisciplinary training are expected to transfer and integrate their disciplinary knowledge with each other. KI requires a set of competencies to process a vast body of information from various perspectives to address complex problems, and it is not easy to acquire these competencies (Xue, Le Bot, Van Petegem, & van Wieringen, 2018). Indeed, several scholars argued that many interdisciplinary projects do not result in significant integration across disciplinary perspectives (e.g., Roy et al., 2013). Disciplinary differences, as well as the structure of academic organizations, all tend to impede KI (Klein, 2011). Researchers investigated KI from different perspectives (e.g., organizational science, team science) and proposed models for KI, however, the empirical evidence of the process of KI is limited (e.g., Pennington, 2016).

In this study, given the complexities of working in interdisciplinary training, we assume that the complexity of KI may lead to more KT relations relative to KI relations between participants. Indeed, two social network studies investigating interdisciplinary collaborations seem to support this assumption (Rhoten, 2003; Haythornthwaite, 2006). However, neither study tested the statistical significance of the difference between KT and KI relations. Furthermore, to the best of our knowledge, no study has looked at how interdisciplinary KT and KI are developed, maintained and sustained over time.

The first research question (RQ1) of this study was: To what extent are there more KT relations developed relative to KI relations by participants during online interdisciplinary training?

Intervening factors on KT and KI relations

There is a range of mediating factors that might influence how KT and KI relations develop over time in an interdisciplinary training, for example, the group composition (how groups of students are composed), mentorship (the relation between students and the supervisor), disciplinary field, previous collaboration experience and gender (Rienties & Heliot 2018; Ryser, Halseth, & Thien, 2009). Putting learners in smaller groups to work on complex interdisciplinary tasks is a common approach in interdisciplinary programmes (Lyall et al, 2015). It is expected that the group composition will influence learning relations between students from different disciplines during interdisciplinary training (Rienties & Heliot 2018).

Besides this, the mentorship including student-supervisor and student-student mentoring plays an important role in interdisciplinary learning and engagement of students (Ryser et al., 2009; Vanstone et al., 2013). Moreover, it has been suggested that participants from neighbouring disciplinary fields might integrate more knowledge compared to participants from distant disciplinary fields (Porter & Rafols, 2009). Furthermore, previous collaboration experience might positively influence interdisciplinary learning (Cummings & Kiesler, 2008). In addition, Ryser et al. (2009) reported that female students find it easier to be open and to bring up issues around their female peers than male peers. These studies implied intervening factors for interdisciplinary learning but did not reveal how these factors affect specifically the development of KT and KI relations, especially in an online training context.

The second research question (RQ2) was: To what extent do group composition, mentorship, disciplinary field, previous collaboration experience, and gender predict the KT and KI relations?

Doctoral students' perspective on KT and KI relations

The final part of this study focusses on the qualitative, lived experiences of doctoral students in our interdisciplinary training. Doctoral students' experience in developing learning relations in interdisciplinary collaboration is critical to improving the design and delivery of interdisciplinary training. A few studies investigated the doctoral students' perspectives in their pursuit of interdisciplinary studies (Boden, Borrego, & Newswander, 2011; Lindvig, 2018; Su, 2016). For example, Su (2016) reported the importance of open-mindedness (such as appreciating different approaches and perspectives) and the importance of willingness to explore a different disciplinary language during interdisciplinary communication. Lindvig (2018) reported the conundrum that students have to fit into a confined disciplinary role, while simultaneously needing to cross boundaries and deliver predefined goals in the interdisciplinary research projects. Researchers also reported that from doctoral students' perspectives, the appreciation of interdisciplinarity, shared student workspace, programme structures, and administrative efforts are important for engagement in interdisciplinary projects (Boden at al., 2011; Calatrava Moreno & Danowitz, 2016).

The third research question (RQ3) was: What are the doctoral students' perspectives on KT and KI relations during online interdisciplinary training?

Methods

In this study, we used a mixed-methods approach combining longitudinal social network analysis (SNA) and qualitative methods to investigate KT and KI relations of doctoral students. SNA is a set of quantitative and descriptive techniques based on the graph and network theory to study interaction structures (Wasserman & Faust, 1994). Grounded in systematic empirical data, SNA reveals the patterns of learning relations

among individuals, for example, to visualise the knowledge flow among learners as networks and to investigate the formation of learning relations. Particularly, SNA is well suited to studying online learning (Cela et al., 2015). For RQ1 and RQ2, we used well-established statistical procedures in SNA to explore the KT and KI relations longitudinally (Dekker, Krackhardt, & Snijders, 2007; Wasserman & Faust, 1994). For RQ3, we employed a qualitative approach to achieve a more comprehensive understanding of the longitudinal network patterns of KT and KI relations during the online interdisciplinary training. Semi-structured interviews were conducted to triangulate the SNA findings.

Setting and participants

This study was conducted within a series of online interdisciplinary training modules in a European project dealing with hearing impairment. The aim of these modules was to provide training to doctoral students from different disciplines who are involved in optimizing the auditory rehabilitation of children with hearing impairment. In addition to the online modules, this EU project also provided face-to-face interdisciplinary training activities including winter schools and secondments. A relatively small sample of 15 participants (10 doctoral students, 2 postdocs and 3 supervisors) from nine institutions in six European countries participated in the online modules. The disciplines of the participants were different from each other, but they could be roughly grouped into three categories: auditory-hearing (n=4), cognition-psychology (n=7), and engineering (n=4). Eight participants were female and seven were male. These modules spanned seven months in total in 2017. At that time, most doctoral students started the third year of their Ph.D. Completing the online modules was required by the project but was not counted as credits.

The online modules included 'introduction to psychoacoustics', 'emerging communication' and 'introduction to executive functions'. The modules were developed by three supervisors and delivered in the learning platform 'Sofia' (https://www.sofialearn.com/app/course/vkd338). The design of the modules was based on the 4C/ID model (Van Merriënboer & Kester, 2005) and for a detailed description of the expected learning outcomes of this training we refer to our previous study (Xue et al., 2018). Each module included three parts: individual learning (web-delivered course content), group work (web-based communication and collaboration), and a webinar. The main aim of the individual learning phase in each module was knowledge transfer on the topics of the course content (e.g., 'introduction to psychoacoustics'). Ten doctoral students and 2 postdocs studied the contents and completed exercises on their own during a three-week period. The main aim of the group work phase in each module was to create interdisciplinary collaboration and knowledge integration from different disciplinary perspectives. The twelve students (including 2 postdocs) were specifically sampled into three groups of four members to maximize diversity in terms of disciplines and institutions. Each group was asked to finish a task in three weeks on Google Docs that required multiple disciplinary perspectives from the group members. The group reports were assessed by the respective supervisor according to the task descriptions. In each module, students were assigned to a different group. Finally, a webinar was organised two weeks after the group work to finish the module by discussing all the group reports. The discussions were led by the respective supervisors.

Data collection

We administered four online surveys to collect SNA data from the 15 participants at four time points to track changes in their learning networks: baseline-before the starting of the online training, T1-after online module 1, T2-after online module 2, and T3-after

online module 3. A pilot study was employed in a similar interdisciplinary learning context four months prior to this study to test the content validity of the survey. To obtain data of KT relations, we required participants to indicate a maximum of six persons from the list of 15 participants they have learned from or received help in understanding something that is not in their own discipline over the period of one module. To obtain data on KI relations, we required participants to indicate a maximum of six persons from the list they turned to in order to discuss ideas integrating different disciplines over the period of one module. For all of the four SNA surveys, response rates of 100 percent were achieved.

After the collection of the longitudinal SNA data, visualisations of the social network graphs were produced to triangulate the quantitative data with a qualitative research phase. In order to gain an in-depth understanding of the doctoral students' experience of KT and KI relations, we selected half of the student participants (n=6) who presented in all the nine groups (in group work phase) during the training for interviews. Per discipline category (auditory-hearing, cognition-psychology, and engineering) two participants were interviewed. The six participants took both central and periphery network positions. They included three males and three females from five institutions in five European countries. The interviews were conducted through online meetings. In the interviews, we used two slides presenting the KT and KI networks at the four mentioned time points as a visual aid to ensure a safe environment to elicit in-depth thoughts and reflections (Bahn & Barratt-Pugh, 2013). All interviews were conducted individually with an average of 50 minutes (SD=16 minutes). The interviews were guided by a semi-structured interview protocol with intentions to find out the reasons for the formation of KT and KI networks. The questions included: From the visualization we can see that the KT and KI networks were more connected at one time

point than at another time point. What could be the reasons? Why did the KT and KI networks seem to have different connection levels from the visualization? How did the group work experience affect your KT and KI relations during the online training? All interviews were recorded, transcribed for analysis and then anonymized. This study was approved by the Medical Ethical Committee of the University. Informed consent from participants was obtained for the survey and interviews. Participants were assured of the anonymity of the data in any reports related to this study.

Data analysis

We used UciNet 6 (Bogatti, Everett, & Freeman, 2002) to analyse the SNA data. To answer RQ1, i.e., to what extent KT relations were developed more than KI relations during the training, we compared the density difference between KT and KI networks at four time points (baseline, T1, T2, and T3). The density of a network shows the degree to which the members of the network are connected with each other, and is often referred to as an overall measure of interaction (Wasserman & Faust, 1994). A bootstrap paired sample t-test was employed by the software to test the significance of the density difference between KT and KI networks.

To answer RQ2, i.e., to what extent the five factors could predict KT and KI relations, we conducted Quadratic assignment procedure (QAP) correlations and QAP regression (Dekker et al., 2007). QAP correlation calculates the extent to which the pattern of connections in one network (e.g., working in the same group) is similar to the patterns observed in the KT and KI networks. We constructed matrices of group composition (at T1, T2 and T3), mentorship, disciplinary category, and gender to represent connections among the participants. The previous collaboration experience was represented by matrices of KT and KI at baseline, T1, and T2. On the basis of the QAP correlation test, we investigated if the connections among the participants

(matrices) could predict the KT and KI connections using QAP regression. QAP regression assesses the significance of the R-square and regression coefficients using double semi-partialling (Dekker et al., 2007).

To address RQ3 regarding the doctoral students' perspectives on KT and KI during online interdisciplinary training, we analysed the transcribed qualitative data using thematic analysis following the guidelines recommended by Braun and Clarke (2006). A deductive approach was used to code the themes. Emerging themes were included during the iterative coding process. In order to ensure the reliability of our coding system, after the first author did the initial thematic codes, the second and third authors coded a selection of the transcriptions independently. Any incongruent themes were discussed before achieving consensus. The themes generated from this analysis were used to triangulate the interpretation of the quantitative SNA results.

Results

RQ1 More KT relations than KI relations observed

Fig. 1 to Fig. 8 visualize the KT and KI relation networks at the four time points. Fig. 1 shows the KT and Fig. 2 the KI networks at the baseline measured before the first online module started. The 15 nodes represent the 15 participants and the lines represent the KT relation with the arrow pointing to the person whom he/she learned from. The three shapes of the nodes represent the three discipline categories of the participants (circle: psychology-cognition; square: auditory-hearing; triangle: engineering). The colours of the nodes in Fig. 3 to Fig. 8 represent the respective groups that the doctoral students were assigned to (pink: group 1, blue: group 2, black: group 3, white: supervisors, grey: absent. Fig. 1 and Fig. 2 have no coloured nodes because the participants were not yet assigned in groups at baseline.).
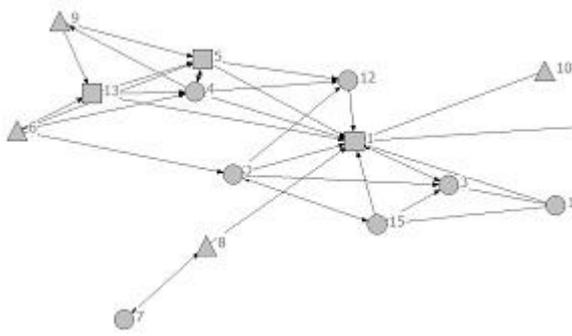
Figure 1. KT network at baseline
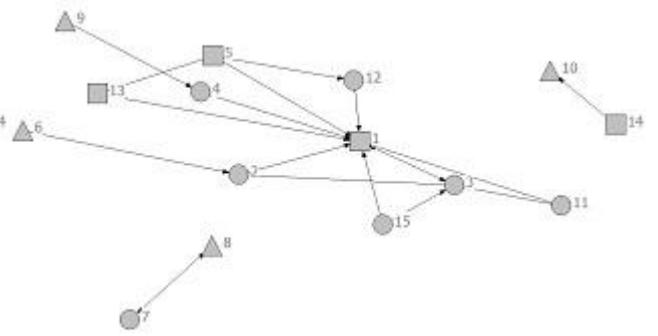

Figure 2. KI network at baseline
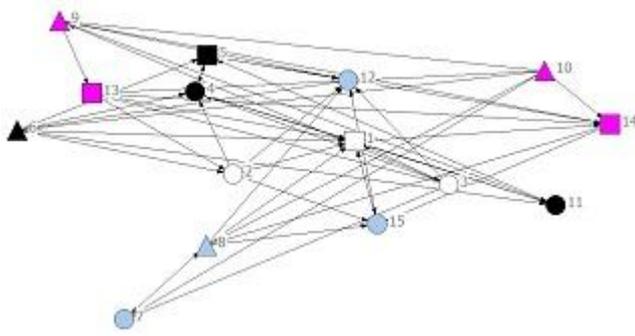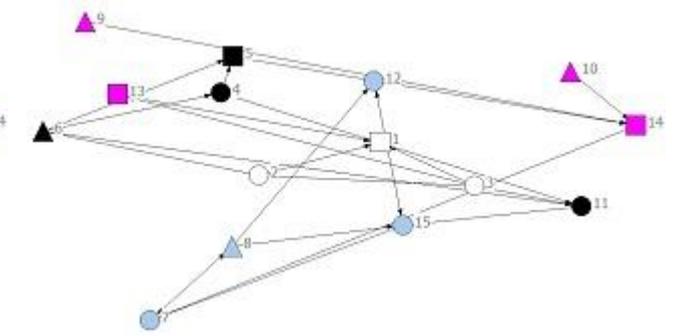

Figure 3. KT network at T1

Figure 4. KI network at T1
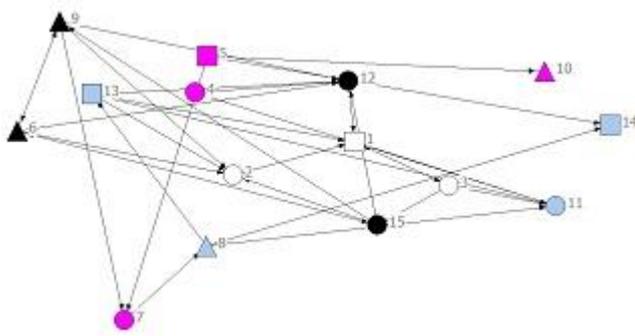

Figure 5. KT network at T2
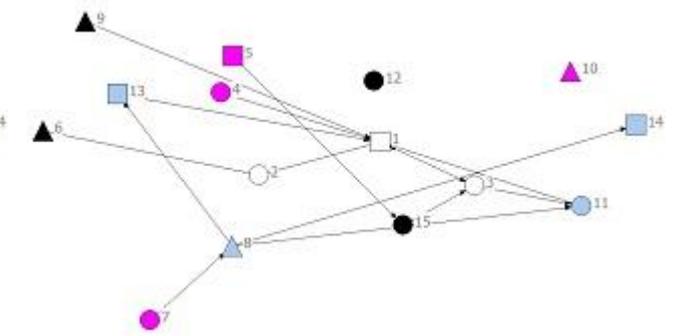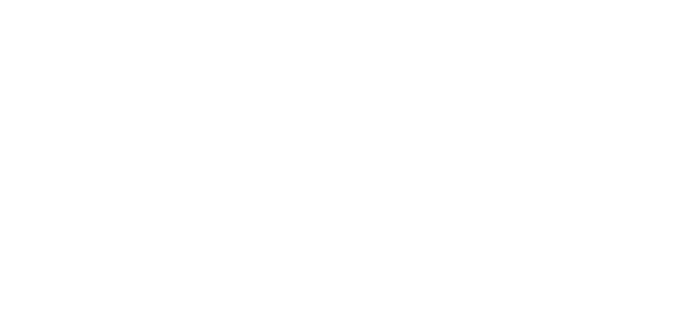

Figure 6. KI network at T2

Figure 7. KT network at T3

Figure 8. KI network at T3
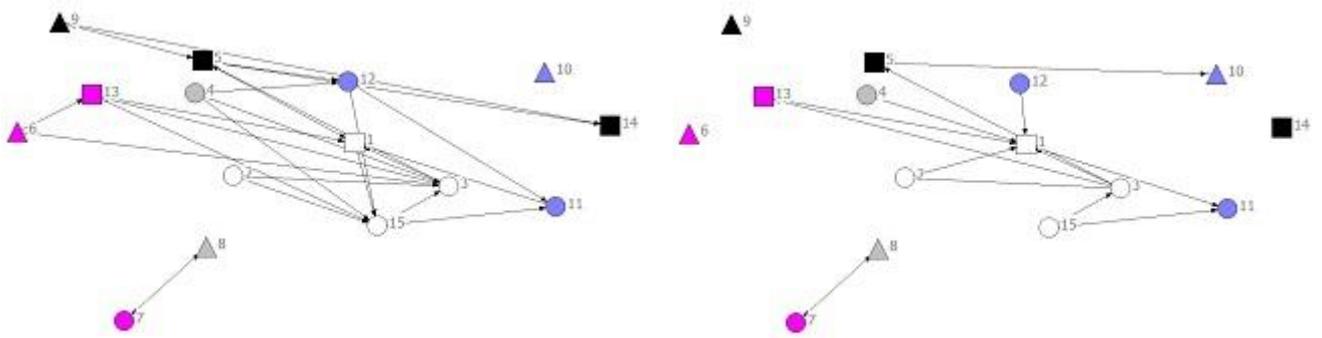
It is evident from the visualization that all KT networks (Fig. 1, 3, 5, 7) are more densely connected than KI networks (Fig. 2, 4, 6, 8) at the four time points. These data suggest that many participants reported learning knowledge from other participants during the period of online interdisciplinary training, but relatively few participants expressed that they integrated disciplinary knowledge or insights when interacting with other participants during this period. Table 1 shows the network densities and the number of reported KT and KI relations at the four time points.

Table 1. Density of KT and KI networks during online interdisciplinary training

Time	No. of Nodes	KT networks		KI networks	
		Density	No. of connections	Density	No. of connections
Baseline	15	0.191	40	0.100	21
T1	15	0.276	58	0.129	27
T2	15	0.171	36	0.081	17
T3	15	0.129	27	0.071	15

A bootstrap paired t-test shows that the density of the KT network was significantly higher than the density of the KI network at all four time points (baseline: $t = 2.379$, p (one-tailed) < 0.05; T1: $t = 3.254$, p (one-tailed) < 0.01; T2: $t = 2.528$, p (one-tailed) < 0.05; T3: $t = 1.709$, p (one-tailed) < 0.05).

RQ2 Group work predicted KT but less KI relations

In order to understand how factors like mentorship and group work influenced KT and KI, we first conducted QAP correlations (not illustrated), and secondly conducted QAP regressions. Table 2 shows the results of these regression analyses of KT networks, and Table 3 shows the results of KI networks (4 regression models for the four time points in each Table). The analysis results show that, before the start of online training, KT and KI networks were positively predicted by mentorship (Table 2, model 1, β=0.460, p<0.001; Table 3, model 1, β=0.411, p<0.001). However, after the start of the online training, the mentorship did not predict KT and KI networks anymore. The respective group composition within the online training significantly predicted KT relations, but to a less degree KI. For example, as shown in Table 2, the main factor that predicted KT networks was the group composition at T1, T2 and T3 (model 2, β=0.407, p<0.001; model 3, β=0.418, p<0.001; model 4, β=0.249, p<0.01). This means that if participants belonged to the same group, the probability of them having KT relations increased 40.7%, 41.8% and 24.9% respectively at T1, T2 and T3 (though the influence of group composition on KT relations seems to vary in the different modules). In contrast, as shown in Table 3, the influence of group composition was only evident in KI networks at T1 (model 2, β=0.511, p<0.001). At T2 and T3, the main factor predicting KI networks was the previous KI experience at baseline (model 3, β=0.308, p<0.001; model 4, β=0.463, p<0.001).

Table 2. Regression analysis of KT networks (standardized coefficients)

	KT-Baseline	KT-T1	KT-T2	KT-T3
	model 1	model 2	model 3	model 4
Discipline	0.001	0.010	-0.010	0.108*
Gender	0.065	-0.033	-0.086	-0.013
Mentorship	0.460***	-0.114	0.093	-0.014
KT-Baseline		0.260**	0.066	0.048
KI-Baseline		0.023	0.115	0.241**

Group-T1		0.407***	-0.160*	-0.103
KT-T1			0.095	0.031
KI-T1			0.138*	0.185*
Group-T2			0.418***	-0.045
KT-T2				-0.013
KI-T2				0.029
Group-T3				0.249**
Adj R-Sqr	0.200	0.226	0.235	0.186

(***p<0.001, **p<0.01, *p<0.05)

Table 3. Regression analysis of KI networks (standardized coefficients)

	KI- Baseline	KI-T1	KI-T2	KI-T3
	model 1	model 2	model 3	model 4
Discipline	-0.078	-0.003	-0.013	-0.021
Gender	0.072	-0.057	0.026	0.082
Mentorship	0.411***	0.056	0.055	0.024
KT-Baseline		0.111	0.132	-0.072
KI-Baseline		0.091	0.308***	0.463***
Group-T1		0.511***	-0.124	-0.109
KT-T1			-0.008	0.046
KI-T1			0.140*	0.182**
Group-T2			0.123*	0.006
KT-T2				0.061
KI-T2				0.081
Group-T3				0.015
Adj R-Sqr	0.155	0.297	0.193	0.282

(***p<0.001, **p<0.01, *p<0.05)

RQ3 Themes of doctoral students' perspectives on KT and KI relations

Three major themes emerged from the analysis of interviews on the doctoral students' experience and reflections of KT and KI relations during online interdisciplinary training. Table 4 shows the major themes (challenges of online settings, training modules design, and student involvement) and the sub-themes for the qualitative analysis.

Table 4. Themes for the qualitative analysis

Major themes	Sub-themes
Challenges of online settings	Strength of face-to-face interaction

	Restraints of online settings
Training modules design	Links between topics
	Group work task
	Timing of the training
Student involvement	Balancing own research and interdisciplinary studies
	Common projects

Challenges of online settings

This theme included two sub-themes: the strength of face-to-face interaction and restraints of online settings to KT and KI relations.

All interviewed participants agreed that face-to-face interaction was beneficial for both KT and KI in an online learning context. During the period of online module 1, a 3-day winter school was held and all the participants presented their research and met each other in person. In addition, the participants also had a one-hour session to practice the group work together. As participant 11 (node 11 in the visualization) commented:

> For the first one (module), we were really interested in doing that because as we started with face-to-face interaction, we recognized how many different things we know about that topic, and how much actually we can learn from the other people.

For some participants, face-to-face interaction in group work built a good foundation for future online learning relations.

According to the participants interviewed, KI relations were restrained more than KT by the online settings. KT relations could develop easily in group work and webinars during online training. However, the development of KI relations in an online setting required more conditions, for example, the convenience of interaction and strong connections between participants. In this study, the geographic distance between the participants limited both these two conditions.

Training modules design

This theme included three sub-themes: the links between topics, the group work task, and the timing of the training. These sub-themes provided insights on why KI relations were developed less than KT, and why group work had less impact on KI than KT in this study.

First of all, in order to ensure interdisciplinary KI, it is important to find links between different research fields or topics. However, finding those links was not an easy task due to, for example, the module topics being too specific to the current research areas of the participants. As Participant 5 remarked:

> I certainly find it ('introduction to executive functions') interesting. So for many people, it is. But it may not necessarily have anything to do with your own project.

Participant 10 (node 10) had a similar comment that they could always learn from each other, but KI depended on how close their topics were. Participant 8 (node 8) who had developed a new interdisciplinary research project with another participant in this European project confirmed:

> The difficult part (for interdisciplinary work) is that you have to find a common ground for discussion.

His opinion was that KI did not necessarily have to be linked to one's actual topic. Any methods or strategies in research could be integrated into one's toolbox and this could help his/her research process.

The group work task was another sub-theme that emerged from the interviews. The participants explained that their approaches to solving the group task could limit the building of KI relations, because they divided the workload without much discussion and most made minimum effort to finish it. Apart from the limitations of online

interaction, another reason for less KI was that participants had different knowledge levels on the group tasks. As participant 10 and participant 12 remarked, it was difficult to integrate knowledge from the group members when nobody was an expert for the tasks and nobody had a strong perspective on them.

The timing of the online interdisciplinary training (around the third year in Ph.D. research) might affect the development of KI relations, due to the doctoral students' research track and other obligations. Three participants assumed more KI relations if the training was provided at the beginning of their Ph.D. trajectory in order to optimize possibilities to integrate knowledge from other disciplines into their own research plans.

Student involvement

Insufficient student involvement in some groups may explain different effects of group composition on KT and KI networks in different modules, as well as the difference between the numbers of KI and KT relations. This theme included two sub-themes: balancing own research and interdisciplinary studies, and common projects.

The participants interviewed often mentioned they had to balance the efforts for their own project and for an extra interdisciplinary topic with KI. As the pressure to finish their own Ph.D. project was huge, even if there were a potential idea of KI, some of them did not explore that much as they would have liked to. Participant 13 commented:

> But for someone who is in a focused group they wouldn't feel that they need to integrate way too much because it takes from the energy that they need to focus on their research.

Opposite opinions also existed. Participant 8 remarked:

But still if you find some interesting umbrella topics that can combine both research areas, that's still worth to try to start a project together.

Having a common research project was suggested by some participants for enhancing KT and especially KI. Participant 8 remarked from his own experience of developing an interdisciplinary research project with another participant:

If you start a project together or a study, the knowledge integration has to be a very strong connection between two points (persons) here, otherwise, it is not working.

Participant 11 remarked:

As Ph.D. students, we are just restricted in the time: we have to do everything we are supposed to do. So I think if we have a structured collaboration with some output, then I think people would be much more motivated to invest time.

Several participants expressed their willingness to do a joint project together, however, due to the different research context of each participant, not every doctoral student started a common project.

Discussion

Online interdisciplinary training for doctoral students is an emerging field in higher education. In this study, by investigating the network patterns of KI and KT relations, we gained insights on the challenges and recommendations for online interdisciplinary training. The SNA (quantitative) results of this study highlight that KT relations were developed more than KI relations in an online interdisciplinary learning context (RQ1). This finding is in line with a previous study for a face-to-face learning context (Haythornthwaite, 2006).

A new discovery by SNA in this study is that the group composition had a greater influence on KT relations than on KI (RQ2). The SNA findings suggest that KI

relations might require more conditions to develop than KT. In terms of RQ3, the qualitative results explained why KI relations were less developed than KT and why group work had a less predicting effect on KI relations than KT from three aspects: challenges of online settings, training modules design, and student involvement. These insights show the importance of interpersonal exchanges in interdisciplinary collaboration, the specific challenges that doctoral students face in their interdisciplinary learning process, as well as the directions for educators to better facilitate interdisciplinary training.

Recommendations

Three implications were gained from this study focusing on enhancing interdisciplinary training for doctoral students. First, KI does not come easily. It is worth mentioning that the roles of mentors in the interdisciplinary exploration of doctoral students are not fully understood (Lindvig, 2018; Lyall et al., 2015; Vanstone et al., 2013). Therefore, we suggest that educators actively try to enhance KI relations. They could, for example, strengthen ties between participants by facilitating regular communication, or providing a common space for the participants (Friedman & Worden, 2016). Or, they could help students to find links between disciplines. In this study, only 3 out of 14 (co)supervisors of the doctoral students participated in the online interdisciplinary training modules.

Second, group learning is beneficial for KT relations, but has less impact on KI relations. Therefore, it is important to have learning groups composed of students from different disciplines to promote KT relations. However, additional measures for group learning should be taken to also enhance KI relations, e.g. designing group tasks in such a way that they could engage participants with different backgrounds and different needs. Group task characteristics were related to perceived knowledge increase in group

learning activities in higher education (De Hei, Admiraal, Sjoer, & Strijbos, 2018).

Selecting an appropriate group task for interdisciplinary training is challenging because

of the different knowledge levels of learners, as well as the disciplinary differences

(e.g., teaching practices, ways to approaching problems) between the learners and

course providers. An interdisciplinary task framework that includes three levels of

interaction between disciplines might help improve the design of interdisciplinary group

work (Gouvea, Sawtelle, Geller, & Turpen, 2013). The above two recommendations

overlap the expertise of enhancing interdisciplinary teamwork, including team structure

and team processing (Xyrichis & Lowton, 2008). It is beneficial to incorporate

perspectives of the team working when designing interdisciplinary training.

Third, during (online) interdisciplinary training, KT relations might be

developed much more than KI. Being aware of this, educators may need to conduct

specific instructional design activities for KT and KI relations separately (for example,

to set KT and KI as different learning goals, and to design different learning activities to

develop KT and KI). Approaching KT and KI differently in the design of

interdisciplinary training might help educators better understand the stages of KT and

KI of doctoral students in their learning processes in order to improve the effectiveness

of educational practice.

Future work

The SNA findings of this exploratory study reveal a number of possibilities to further

investigate the learning relations of KT and KI as well as the interdisciplinary learning

process. For example, some participants were positioned centrally and some were

positioned in the periphery of the networks. Future research should investigate in more

detail what causes the different network positions (e.g., Does discipline affect the

network position of the participants?). Furthermore, it is important to study how these network positions relate to the KT and KI outcomes of participants. It might also be worthy to investigate how KT and KI relations might affect the future career development of doctoral students. Our qualitative findings suggest that students perceived difficulties in finding links between different disciplines. We suggest future research to investigate supervisors' perspectives regarding facilitating doctoral students to find links between different disciplines during interdisciplinary supervision.

Limitations

The first limitation of this study is the relatively small sample size. Given the relatively small sample size and high member heterogeneity, the findings of this study have to be interpreted with care. To mitigate this limitation, the methodology of the current study is based on previous studies that applied SNA to small samples (e.g., Sibbald, Wathen, Kothari & Day, 2013). We adopted a longitudinal network approach and combined it with a qualitative approach to gain a comprehensive understanding. The second limitation of this study is the self-reporting nature of the SNA method, in which perceived socially desirable behaviour may have influenced the results. However, in this study, we had a 100% response rate for all of the four surveys. The high response rate might mitigate this limitation (Ter Wal & Boschma, 2009). Another limitation could be that the training had to be provided in the third year of the doctoral students due to the specific context of this EU project. The qualitative findings in this study suggest that more KI relations could be established if the training was provided earlier. However, it needs to be examined to which extent the delivery time of interdisciplinary training affects the development of KT and KI relations.

Conclusions

Interdisciplinary training for doctoral students is an emerging scenario in higher education. The learning relations of the students during the training is critical for the learning process, but limited understanding is available regarding this topic. This study provides insights into the learning relations of KT and KI of doctoral students in an online context, contributing to the enhancement of interdisciplinary training (especially in small-sized projects). Using a mixed approach combining longitudinal SNA and qualitative analysis, this study explored patterns of interdisciplinary KT and KI relations, as well as the reasons behind these patterns. The quantitative and qualitative findings highlight the scarcity and the challenges of KI relations compared to KT in an online context. Based on the findings, practical implications are drawn for the design of online interdisciplinary training, including suggestions to promote KI, strategies for group learning, and designing separately for KI and KT.

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