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RESEARCH ARTICLE

Supporting interdisciplinary collaborative concept mapping with individual preparation phase

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Abstract

Concept mapping facilitates the externalisation and internalisation of knowledge by individuals during collaborative knowledge construction. However, not much is known about the individual and collaborative learning processes during collaborative concept mapping (CCM) in interdisciplinary knowledge construction. Premised on literature on collaboration scripts to scaffold the collaboration process, this study investigates the effect of an individual preparation phase prior to collaborative work on the epistemic and social processes of knowledge co-construction, as well as the degree of interdisciplinary knowledge integration in collaborative concept mapping. A total of N = 42 third year university students were put into one of the two experimental conditions: with individual preparation phase (WIP) and without individual preparation phase (WOIP). Students worked on a collaborative assignment to integrate interdisciplinary knowledge in collaborative concept mapping. Data for analysis was derived from audio recordings of the collaborative discourse in both experimental conditions. Chi-square test was conducted to investigate if there were significant differences between the effects of WIP and WOIP on the epistemological and social dimension. Findings showed that groups in the WIP condition showed significantly more verification, clarification and positioning statements in the epistemic dimension and also significantly more integration-oriented and conflict-oriented consensus building in the social dimension as compared to groups in the WOIP condition. On the degree of interdisciplinary knowledge integration, independent sample t-tests showed that there was no significant difference for concepts, domains and cross-links between the two experimental conditions. However, there was significant difference in types of cross-links for the CCMs in the WIP condition.

Keywords Collaborative concept map · Knowledge co-construction · Interdisciplinary knowledge integration · Common ground · Epistemic processes · Social processes

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Introduction

Contemporary socio-economic problems very often require the integration and synthesis of knowledge from various disciplines for optimal solutions. Take for instance, to address challenges in digital and social media marketing, knowledge in marketing trends, engagement patterns of core stakeholders, and socio-economic status of the target users would be needed to obtain robust solutions. Knowledge integration entails identifying differences and/or recognising connections between and amongst seemingly similar concepts or principles, as well as integrating a range of experiences to co-construct and/or advance existing knowledge. However, the process of knowledge integration is fraught with challenges in the epistemic as well as social processes during interdisciplinary knowledge integration. There are conditions to be met for successful knowledge integration. For new ideas to be understood, they have to be connected to related ideas, used to interpret existing ideas and finally applied in different contexts (Schwendimann and Linn 2016). This would mean synthesising concepts and ideas from different disciplines and domains into a coherent whole. Next, challenges in the social-cognitive processes ensue when individuals and/ or groups from the various disciplines come together to negotiate different knowledge, concepts and experiences to construct shared meaning and knowledge.

To overcome impasses in coordination, communication and interaction to integrate knowledge and construct shared knowledge, concept mapping is one effective measure to scaffold the complex process of interdisciplinary thinking. Novak and Cañas's (2006) empirical work has shown that collaborative concept map (CCM) plays an instrumental role in facilitating knowledge integration as it provides a graphical representation of concepts and relationships between concepts. CCM enhances coordination and communication between individuals of a group, which in turn, facilitates a more integrated conceptual framework with more types of links between the different concepts (Engelmann and Hesse 2010). On a similar note, Schwendimann and Linn (2016) advocate the use of knowledge integration map (KIM), a form of concept map to facilitate and to foster critical collaborative reflection in the knowledge integration processes. Their study showed that students engaged better in identifying alternative ideas, connecting and integrating ideas. A study by Reiska et al. (2018) also found positive changes in the development of students' interdisciplinary knowledge in science when they analysed students' concept maps and assessed the interdisciplinary learning with the concept mapping interdisciplinary quality index (IQI). Another recent study showed that argumentation scaffold through concept mapping during problem-based learning significantly improved and had a transfer effect on the reasoning skills of medical students (Si et al. 2019). In a similar vein, the findings of a scientific report on students' perceptions of collaborative concept mapping (CCM) found that the CCM facilitated interdisciplinary learning: students were better able to generate interdisciplinary themes, integrate knowledge, construct new understandings and develop solutions for the problem-based assignment (Everett 2019).

As afore-discussed, whilst there has been extensive empirical works on the use of CCM to foster interdisciplinary learning, not much is known about the social processes i.e., how the understanding of the individuals from different disciplines evolves and becomes grounded in the collaborative discourse to arrive at integrated knowledge and shared consensus. The negotiation and integration of shared knowledge to arrive at shared consensus are characterised by the engagement of a series of epistemic activities and collaborative activities in the social processes. In their study on collaborative knowledge co-construction, Weinberger and Fischer's (2006) foreground three levels of shared consensus: quick consensus, integration-oriented and/ or conflict-oriented and they accentuate that the type of consensus is also a reflection of the level of transactivity in the negotiation process. Transactivity is the degree to which learning peers build on one another's knowledge contributions in collaborative learning (Teasley 1997). Transactivity is an indicator of collaborative knowledge integration (Wen et al. 2016) and collaborative reflection is instrumental in the knowledge integration processes (Schwendimann and Linn 2016). The last three decades have witnessed an increasing volume of research on enhancing collaborative learning with instructional scaffolds (Rummel and Spada 2005; Kollar et al. 2011), collaborative reflection activities (Schwendimann and Linn 2016) and/or collaboration scripts and prompts (e.g., Kobbe et al. 2007; Wecker and Fischer 2011), however, there remains a paucity of empirical works on the social processes in collaborative interdisciplinary knowledge integration in CCM.

Hence, this research study gives focus to the individual and group processes in collaborative concept mapping which might provide some insights on facilitating interdisciplinary knowledge integration with learners from multiple disciplines. Specifically, it investigates how embedding an individual preparation phase prior to collaborative work could have an effect on the epistemic and social processes, as well as the degree of interdisciplinary knowledge integration in collaborative concept mapping. In the succeeding sections, we first discuss the epistemic and social processes of knowledge co-construction. Next, we present core theoretical grounding for (collaborative) concept mapping and challenges in facilitating interdisciplinary concept mapping with a focus on the social processes. In the method section, we exemplify the research setting, the field study and the two experimental conditions (WIP and WOIP). The coding schemes for the respective epistemic and social processes, as well as the analytical approach to qualify the level of transactivity are also articulated. Following which, we report and discuss key findings on embedding an individual preparation phase in interdisciplinary collaborative concept mapping. Finally, we surface the limitations in this empirical work and the implications for future work.

Epistemic and social processes in collaborative knowledge construction

The process of integrating knowledge from various disciplines requires a substantial amount of negotiating shared understanding to construct integrated knowledge. Beers, Boshuizen, Kirschner, and Gijselaers (2006) identified four core stages "from unshared knowledge to constructed knowledge": externalisation, internalisation, negotiation and integration. Externalising unshared knowledge is a first step in the knowledge co-construction process. Knowledge externalisation encompasses both externalising and eliciting knowledge. Externalisation means rendering contributions in a collaborative discourse and elicitation refers to requesting information from learning partners (Weinberger and Fischer 2006). Knowledge internalisation, knowledge negotiation and knowledge integration encompass various epistemic activities during the negotiation process to build consensus for the delivery of the eventual constructed/ integrated knowledge. Beers et al. (2006) outlines four core epistemic activities which he coined the 'primitives of negotiation': contribution, clarification, verification and elaboration. Posing questions, seeking clarity and requesting for more information to verify and clarify one's contributions at the group level are critical during the negotiation phase. And to this list of epistemic activities, we added *positioning* where one defends one's ideas, and/or agreeing and disagreeing to peers' contributions with evidential reasoning to establish common ground.

Negotiating common ground in the knowledge integration process involves collaborative regulation of cognitive activities in the social processes. Palincsar's (1998) works foregrounds the 'interdependence of the social and the individual processes' in collaborative knowledge co-construction. The intricate interwoven nature of the individual and social processes imposes high degree of cognitive, metacognitive and socio-cognitive demands. Clark and Brennan (1991) contend that individuals can only begin to coordinate the content after they have collectively negotiated shared information, shared knowledge and shared beliefs. In essence, coordinating the process is instrumental in coordinating the content. Weinberger and Fischer (2006) accentuate five social modes of knowledge co-construction in the social processes: externalisation, elicitation, quick-consensus building, integration-oriented consensus building and conflict-oriented consensus building. The different social modes represent different levels of transactivity. The quality of group discourse is measured by the level of transactivity (Weinberger and Fischer 2006). A high level of transactivity is related to the number of conflict-oriented discussions between peers, as conflict is the source of cognitive growth (Levine and Resnick 1993). Socio-cognitive conflict leads to higher levels of collective cognitive performance (Doise and Mugny 1984). In conflict-oriented consensus building, students critically reject or accept each other's contributions with evidence-based argumentation, modification and/or supplementation. Whereas in quick-consensus building, students can accept each other's contributions without questioning them and in integration-oriented consensus building, students take over or integrate each other's perspectives. As such, the three different modes of arriving at a consensus carry critical implications on the level of transactivity, and inadvertently, the quality of the knowledge product.

In sum, bridging different perspectives and negotiating common ground to construct integrated knowledge hinges on the quality of the collaborative discourse in the epistemic and social processes of the knowledge integration and co-construction process. The degree of shared consensus i.e., quick consensus, integration-oriented and/ or conflict-oriented is contingent on the types of epistemic activities such as verification, clarification, elaboration and positioning.

Facilitating interdisciplinary collaborative concept mapping

In interdisciplinary knowledge co-construction, members will have to analyse a given problem from multidisciplinary perspectives and to synthesise and integrate knowledge across disciplines to arrive at a robust solution. The core cognitive task in this complex process is knowledge integration. To facilitate the cognitive process of interdisciplinary thinking, collaborative concept mapping is one of the key instructional strategies to scaffold the integration process (Everett 2019). Concept mapping primarily facilitates the activation of prior knowledge by enabling learners to structure the individuals' think-processes and to improve their own mental models (Teasley 1995).

Concept mapping embraces principles of some salient and recognised theoretical approaches such as activity theory (Leontyev 1978; Vygotsky 1978), Paivio's (1986) dual coding theory, cognitive load theory (Janssen and Kirschner 2020; Kirschner et al. 2018), embodied cognition with enactivism (Galetzka 2017), and distributed cognition (Salomon 1997; Stahl 2006; Van den Bossche et al. 2011). At its core, concept mapping supports reasoning with external representations which provides a platform for learners to present and to externalise their individual contributions and ideas (Stoyanova and Kommers 2002). Externalisation by means of external representations facilitates the transfer of complex information between cognitive sub-systems in ways that are not possible internally according to the dual-coding hypothesis (e.g. Paivio 1986). Constructing and interacting with external representations facilitates effective internationalisation of the mental operations (Vygotsky 1978). The externalisation/internalisation dimension is closely related to individual/social dimension in learning activity mediated by a tool such as concept mapping. When internal activity is externalised, it also activates actions that can be shared and thus enabled social distribution of these actions. Physical drawing of a concept map, including manipulation of nodes and links, either manually or by software can also contribute to developing cognitive structure according to embodied cognition and enactivism (Galetzka 2017). Embodied cognition epitomises the notion of *making thinking visible* in effective instructional strategy (emphasis mine). Hence, the concept mapping process is instrumental in making thinking visible by *making it enactable and manipulable* (emphasis mine). In other words, the perception of visual cues (e.g., hands/arms gestures, body movements, and facial expressions) of fellow learning peers during the co-creating of a collaborative concept mapping supports the internalisation of cognitive structures and processes (Danish et al. 2020). Next, while concept mapping applies simple structural features (nodes and labelled links), it is at the same time, rich in information owing to the integration of verbal and visual coding (Paivio 1986). The technique capitalises on the advantages of graphical representations without losing the flexibility and richness of the natural language system. Concept map has a potential to reduce the cognitive load, because it is an external extension of working memory either of an individual or a group (Janssen and Kirshner 2020; Kirschner et al. 2018). In addition, the externalisation of mental cognitive representations also frees up cognitive resources necessary for memory and reasoning. In other words, concept mapping structures knowledge: it scaffolds the externalisation of knowledge (Schmid et al. 2002), as well as the internalisation of knowledge much more effectively as compared to written texts (Engelmann and Hesse 2010).

Research showed that a concept map not only structures the collaborative discourse, but also fosters more in-depth and productive interaction (Sizmur and Osborne 1997). The explicit representation of individual mental models in concept mapping provides the essential platform for the collaborative grounding process where concepts and relationships between concepts can be more effectively negotiated (Stoyanova and Kommers 2002). Collaborative concept mapping are examples of shared mental models and distributed cognition (Salomon 1997; Stahl 2006; Van den Bossche et al. 2011). In interdisciplinary collaborative concept mapping, learning peers are required to get an accurate idea of what the others from a different discipline have shared (Engelmann and Hesse 2010). Collaborative mapping not only fosters the exchange of ideas (Novak and Cañas 2006), it also facilitates interdisciplinary thinking where students make connections of ideas across two or more disciplines (Everett 2019). This leads to better knowledge synthesis and the eventual integration of different knowledge contribution as concept mapping enables a visual representation of abstract concepts and relationships, as well as implicit knowledge (Nesbit and Adesope 2006; van Boxtel et al. 2002). In a nutshell, collaborative mapping process fosters interdisciplinary knowledge integration by making the connections between disciplinary insights visible: enable students to generate, integrate and consequently construct new knowledge and devise robust solutions for problems (Everett 2019).

While there has been substantial evidence from the aforementioned literature and empirical studies that collaborative mapping enhances interdisciplinary thinking, learning and knowledge integration, there remains little systemic empirical studies on the social processes in collaborative interdisciplinary concept mapping. Social processes of achieving a consensus is the centerpiece in negotiating and integrating shared understanding of different disciplinary knowledge to co-construct new knowledge (Schwendimann and Linn 2016). Therefore, in this empirical study, we are interested to investigate whether an individual preparation phase prior to the collaborative concept mapping would better prepare the individuals in integrative understanding at the collective level. The succeeding sections discuss theoretical arguments for and against an individual preparation phase.

With individual preparation phase

The three main theoretical arguments for an individual preparatory phase are: (i) more time and space for personal reflection and for the development of an individual mental model; (ii) better preparation for knowledge negotiation and a shared focus; and (iii) more openness to the contributions of other individuals in the group.

Collaborative concept mapping is a transformative process that requires several iterations before arriving at an optimal knowledge representation. Gao's (2007) studies on collaborative concept mapping found that individual work phase enabled the learners to organise their thoughts and present their ideas more effectively at the collaborative phase. This is because although shared group cognition is commonly conceived as the sum of all individual distributed cognition systems, this phenomenon cannot be understood without an explicit reference to individual mental representations (Salomon 1997; Stahl 2006). Before we can speak of shared representations, individual knowledge representations need to be developed independently. In a similar fashion, constructing a concept map individually primarily helps balance the cognitive load in a complex task. Hence, managing individual cognitive load is beneficial for effectively managing collective working memory load. In addition, it is through the individual concept mapping preparation stage that students know if the task exceeds their individual cognitive capacity so they could apply the mutual interdependence principle of collective cognitive load theory (Janssen and Kirshner 2020; Kirschner et al. 2018). This principle of human cognitive architecture postulates that effective learning depends on mutual and simultaneous relationship between different cognitive systems such as information processing systems of students, teacher's cognitive system operationalised through instruction, but also interaction of these cognitive systems with the environment. Collective cognitive load and shared group cognition are intrinsically connected through the mutual interdependence principle. Individual preparation phase, therefore, allows the individuals more room to reflect on the content, as well as to develop ideas and arguments to support those claims. Van Boxtel et al.'s (2002) works on collaborative concept mapping showed that students with individual preparation phase pose more questions than students without individual work phase in the knowledge co-construction process. Likewise, Teasley's (1995) study showed that individuals in peer collaboration talked and reasoned more as they wanted to be understood. This is even more pronounced during the negotiation process to integrate knowledge of different individuals to construct shared knowledge. In the concerted effort to establish common ground, the shared status has to be continuously updated to converge at shared meaning and knowledge (Clark and Brenan 1991). The concept of shared status is best understood using Barron's (2006) notion of a 'shared problem space' where he postulates that the collective unit of individuals are better able to pose relevant questions and solutions in the shared problem space. Further, advocates of collaborative knowledge construction contend that the collective disagreements, argumentation and reasoning could advance the state of knowledge. The degree to which learners refer to and build on others' knowledge contributions is a significant signpost on the level of 'transactivity' (Teasley 1995). *Transactivity, discussions and argumentations* are defining features of a successful collaboration (Noroozi et al. 2013; emphasis added). On the same note, Weinberger and Fischer (2006) postulate that transactivity will determine the quality of the collaborative discourse in the knowledge co-construction process. They contend that 'integrated- and conflict-oriented consensus building' statements in the social dimension of collaborative knowledge construction would reflect a higher degree of transactivity whereas more externalization and elicitation statements point to a lower degree of transactivity. Higher level of transactivity implies more verification, clarification and positioning statements as exemplified in Beers et al.'s (2006) primitives of negotiation. By embedding an individual preparation phase prior to collaborative concept mapping, it could enable the individuals to explore ideas, to think through differences and similarities across ideas, perspectives and knowledge. In essence, learners are cognitively more prepared during shared task.

Without individual preparation phase

Theoretical arguments for collaborative concept mapping without an individual preparation phase are: i) joint peer scaffolding; ii) prevents fragmented thinking and ideas; and iii) prevents defensive reasoning and argumentation.

The WOIP (without individual preparation phase) experimental condition exemplifies the theoretical notion of *peer scaffolding*. *Peer scaffolding* foregrounds interaction and collaboration as an important scaffold to enable individuals to acquire complex knowledge and skills (Collins et al. 1989). Peer scaffolding means that the 'better student provides a temporary support' and that this support can be gradually reduced (Rogoff 1990). Akin to Vygotsky's (1978) fundamental idea, high psychological functions develop at two planes: firstly interpsychologically in interaction between people, and secondly, as intrapsychological achievement. Individual learning occurs where one internalises or externalises knowledge that was first constructed with others. Vygotsky advocates interaction with experts and/ or more capable peers as an effective measure to develop skills and strategies. In a similar vein, peer scaffolding process conceives of interaction and collaboration as instructional support to accomplish a complex task which could be impossible or overwhelmingly challenging than doing it alone without assistance. For instance, Tsovaltzi, Judele, Puhl, and Weinberger's (2017) study found that the individual preparation of arguments did not support learners to elaborate on arguments, co-construct arguments and integrate multiple perspectives. In addition, the authors found that individual preparation negatively affected the expected positive role of argumentation script on argument structure. The authors attributed the negative effects to the possibility of copy-pasting arguments from the individual to the collaborative phase. Hence, individual preparation could have a detrimental effect on knowledge co-construction owing to premature knowledge consolidation prior to the group work.

Another compelling argument against an individual preparation phase is to overcome disjointed and incoherent ideas in collaborative knowledge co-construction. The concept of fragmented thinking is best illustrated by Senge's (1990) notion of system thinking ('Systeemdenkers' in the original language) where all parts are not independent of each other as all components are interdependent which necessitates a continuous interaction between the various components. This means that various and diverse aspects/ interdependent elements of the individual parts need to be worked on and presented as a collective whole. Similarly, Basque and Lavoie (2006) contend that a collaborative concept map could be seen as a cognitive system with interaction between the individuals and the collective action is more than the sum of the individual actions. 'Collective action' is also believed to prevent defensive behavior and/ or the inclination to act independently (Argyris 1993). In other words, individuals could be more open to feedback, ideas and contributions when they start on a shared task as a collaborative group, rather than as individuals.

In the light of the aforementioned different theoretical groundings for with- and without individual preparation phase, we did not set up a directed hypothesis, but expected that the two different conditions would yield differences on the interdisciplinary knowledge construction process during collaborative concept mapping. Our research questions are:

RQ 1a To what extent does with- and without-individual preparation phase (WIP & WOIP) affect the epistemic dimension of interdisciplinary collaborative concept mapping?

RQ 1b To what extent does with- and without-individual preparation phase (WIP & WOIP) affect the social dimension of interdisciplinary collaborative concept mapping?

RQ 2 What is the effect of with- and without-individual preparation phase (WIP & WOIP) on the degree of interdisciplinary knowledge integration in collaborative concept mapping?

Methods

Sample and design

A total of N = 42 third year university students in HBO (Hoger Beroeps Onderwijs) participated in this field study. All third-year students were previously engaged in community learning in real-life setting and were thus very familiar with collaborative learning activities. Community learning and collaborative learning share similar theoretical notions of individual and shared cognition as well as mutual interdependency. Collaborative learning forms an important tenet of the educational practice in this university. The 42 students attended a mandatory course on either minor Entrepreneurship or minor Marketing 3.0. Both the minor Marketing 3.0 and the minor Entrepreneurship students have chosen an interdisciplinary approach to broaden their perspectives in the respective fields. The minor Marketing 3.0 targets innovative marketing techniques such as neuromarketing and experience marketing and the minor entrepreneurship students learn about the set-up of a business/ company. They were randomly assigned to one of the two experimental conditions: with and without individual preparation phase (see Table 1). In each of the experimental conditions, there were two groups of minor Marketing 3.0 students from different disciplines—multimedia design, business administration, management and law, marketing, and communication and two groups of minor Entrepreneurship students from various disciplines—multimedia design, business administration, management economics and law, marketing, industrial engineering, computer science and nursing. In total, there are four groups of 5 to 6 students in each of the experimental conditions: one group from WIP minor entrepreneurship has 6 students and one group from WOIP minor entrepreneurship has 6 students (all the other 6 groups have 5 students each).

Table 1 Participants in the experimental design with two conditions

	With individual Preparation phase (WIP)	Without individual Preparation phase (WOIP)
Female	4	3
Male	17	18
Age	M = 23.1	M = 23
Total	N = 21 *4 groups	N = 21 *4 groups

*4 Groups: 2 groups from minor entrepreneurship & 2 groups from marketing 3.0 in each experimental condition

Learning environment

All lessons occurred in a face-to-face setting. During the plenary lecture, students in both conditions were introduced to concept mapping and the CmapTools software. Here, students were taught about the principles of concept mapping, as well as all the different types of relationships and links. They were also given the opportunity to practice constructing concept maps. For the small group collaborative task, students in both experimental conditions were to use CCM to generate ideas and solutions. The collaborative task is a concrete, authentic task that requires the integration of knowledge from multiple disciplines to provide a robust solution. They are intrinsically complex for the students and require systematic efforts at individual and group level. Students in the minor Entrepreneurship had to conduct a macrotrend analysis and students in the minor Marketing 3.0 had to create an innovative marketing mix. The resulting interdisciplinary collaborative concept map from the small groups will culminate in the conceptualisation of a concrete solution to the given collaborative task.

Students in both experimental conditions observed the same duration (1 h 15 min) for their respective tasks (see Table 2). Students in the WIP condition were given 30 min to think through the task individually and also prepared an individual concept map before proceeding to work with the group on a collaborative concept map for 45 min. And for students in the WOIP experimental condition, they proceeded directly to collaborative work for an hour and 15 min, during which they developed a collaborative concept map. At the

Table 2 Overview of learning phases in the two experimental conditions

Lesson phases	With individual preparation phase (WIP)	Without individual Preparation phase (WOIP)
1. Plenary Introductory Lecture on CCM	1 h 30 min	1 h 30 min
2. Individual Preparation Phase (incl. individual concept map)	30 min	N.A
3. Collaborative Concept Mapping (Group task: macro trend analysis or innovative marketing mix using CCM to generate ideas & solutions)	45 min	1 h 15 min
4. Debrief	30 min	30 min
Total Duration	3 h 15 min	3 h 15 min

end of the lesson, all the eight groups were required to present a group concept map for their respective groups. Students in the WIP condition only used their individual concept maps in their small group discussion to work towards a collaborative concept map but were not required to present their individual concept maps. There were no roles assigned to any participant in all the eight groups. One participant from each group volunteered to edit the concept map for their group during the collaborative work phase.

Data analysis

To investigate the degree to which WIP and WOIP differ on the epistemic and social processes in the interdisciplinary collaborative concept mapping, data for analysis was derived from audio recordings of the collaborative discourse in both experimental conditions, i.e., a total of 8 h audio recordings. Chi (1997) proposes the use of semantic boundaries to determine a unit of analysis. Thus, each unit of analysis may contain one or more than one statements depending on the discussion threads, ideas and turn of talks. For the epistemic dimension, there is a total of 2659 units of analysis: 1715 units of analysis for the WIP condition and 944 units of analysis for the WOIP condition. And for the social dimension, there is a total of 2432 units of analysis: 1546 for the WIP condition and 886 units of analysis for the WOIP condition.

To measure the effects of the experimental conditions on the interdisciplinary knowledge construction process, we looked at both the epistemic and social dimension of the collaborative discourse. The coding scheme for the epistemic dimension is adapted from Beers et al. (2006) where concepts and relations between concepts will be coded with regard to: contribution, verification, clarification, elaboration, and positioning (see Table 3). For the social dimension the collaborative discourse was coded according to the five social modes of knowledge co-construction from Weinberger and Fischer (2006) as exemplified in Table 4. The different social modes indicate different levels of transactivity with the lowest level of transactivity being externalisation or elicitation, and the highest level of transactivity being conflict-oriented consensus building (Weinberger and Fischer 2006). Two independent raters were trained to code the epistemic and social dimension of

Table 3 Coding categories of the epistemic dimension (adapted from Beers et al. 2006)

Categories	Descriptor and sample statements
Contribution	Surface an idea/a concept in which a new topic of conversation not discussed before is introduced E.g., I read somewhere that migration is because if you have an increase in the world population and especially in certain countries, there is a shortage of raw materials
Verification	Request information about the intended meaning of a contribution E.g., What do you mean? Migration and short of raw materials
Clarification	React to a verification and/or seek further explanation to check for understanding E.g., More population means more scarcity of goods, more conflicts among themselves
Elaboration	Expand an idea/a concept by adding more information E.g., Yes, but if you read those reports, it is mainly eight countries where it is growing bizarrely and the Netherlands is not one of them …
Positioning	Summarize one's viewpoint and take a position by agreeing, disagreeing, accepting or rejecting E.g., Then you can add that ecological link. I think that it is precisely this shortage of raw materials that causes migration

Table 4 Coding categories of the social dimension (Weinberger and Fischer 2006)

Categories	Descriptor and sample discourse
Externalisation	Contribute to discourse without any explicit or implicit references to previous contribution Student S: I read somewhere that migration is because if you have an increase in the world population and especially in certain countries, there is a shortage of raw materials
Elicitation	Request information/feedback from learning peers Student J: What do you mean? Migration and short of raw materials
Quick consensus building	Accept a peer contribution without any modification Student C: Yes. Migration related to shortage of raw materials
Integration-oriented consensus building	Take over the perspective of their learning peers and/ or integrate different perspectives Student S: More population means more scarcity of goods, more conflicts among themselves. So there is indeed … there is no causal relationship, but there is a correlation. That is an assumption you can make
Conflict-oriented consensus building	Reject and/or repair contributions of their learning peers with further replacement, modification and/ or supplementation Student M: Yes, but if you read those reports, it is mainly eight countries where it is growing bizarrely and the Netherlands is not one of them… Student J: There really is a serious relationship between demographics and the increase in the world's population Student S: I don't think that's a demographic trend Student M: But that is a consequence of the global population increase Student S: But then I think that is an ecological aspect Student M: Then you can add that ecological link. I think that it is precisely this shortage of raw materials that causes migration

the transcribed audio data of the two groups (one in each condition) which constitutes 25% of the total data. The epistemic dimension was measured with a sufficient inter-rater reliability (Cohen's Kappa $\kappa = 0.79$) and for the social dimension, the inter-rater reliability was Cohen's Kappa $\kappa = 0.88$. To examine the extent to which the WIP and WOIP conditions diverge on the epistemological and social dimension of the interdisciplinary knowledge construction process, chi-square test was conducted because the variables were measured at a nominal level. In addition, the column proportions were compared with each other using a z-test and Cramer's V was calculated to determine the strength of the association between the variables. The minimum expected cell frequency assumption was not violated.

For the concept mapping outcome measures, we adapted the scoring scheme proposed by Cañas et al. (2015). It takes into account two main criteria: content and graphical structure. Content of the CCM is operationalised through four indicators, namely: concepts, domains, cross-links, and types of cross-links (see Table 5). A good concept map demonstrates well-organised hierarchical graphical structure. A concept map with hierarchical organisation is considered a better representation of a knowledge domain than concept maps with spoke or chain graphical structure (Kinchin et al. 2019). Spoke graphical structure includes only a single level of conceptual relationships where all related concepts are linked directly to the core concept, but not to each other. There are no crosslinks. A chain concept map has a linear sequence of concepts: Multiple levels

Table 5 Overview of the CCM scoring scheme (Cañas et al. 2015)

Variables	Descriptor
Concepts	Contain one or a few words labeling a specific concept
Domains	Refer to knowledge domain or different sub-domains of knowledge
Cross-links	Specify relationships or links between concepts in different segments or domains of the concept map
Types of cross-links	Refer to causal, pragmatic, correlation, influence, example of sequential, agreement, is part of, is the same as

in relation to the root concept could be observed but there is neither a proper hierarchical organisation, nor cross-links. On the other hand, a hierarchical or network concept map addresses the shortcomings of spoke and chain. Concepts in a hierarchical/network graphical structure clearly show a multiple levels organisation forming a highly integrated network of concepts. The cross links are a substantial part of conceptual structure. A well-organised hierarchical cognitive structure reflecting a domain knowledge structure usually leads to graphically well-organised concept maps (Cañas et al. 2015). Cross-links typically are considered a structural indicator but in this study they specify significant content relationships between two knowledge domains. There are two indicators for cross-links to emphasise their importance: the number of cross-links and the type of cross-links.

Results

This section provides some evidence on the degree to which with- and without-an individual preparation phase differ on the epistemic and social dimensions of interdisciplinary knowledge co-construction in the collaborative concept mapping process as well as the degree of interdisciplinary knowledge integration in the concept maps.

Differences between WIP and WOIP on the epistemic processes

Figure 1 shows the overview of the frequency of occurrences per epistemological category for both experimental conditions: with (WIP) and without individual preparation phase (WOIP). There were overall more occurrences of utterances in all the epistemic processes for students in the WIP condition as compared to students in the WOIP condition.

Using Chi-square test, the frequency distribution of the epistemic processes in the two experimental conditions were compared. There was a significant difference in the epistemological dimension of collaborative knowledge construction between the WIP and the WIOP experimental conditions: χ^2 (5) = 22.85, $p < 0.05$, Cramer's V = 0.14.

In addition to the chi-square test, a z-test was done to compare the column proportions of the WIP groups and the WOIP groups (see Table 6). There were significantly more occurrences of clarification statements, positioning statements and significantly fewer non-task talk in the WIP condition as compared to the WOIP condition.

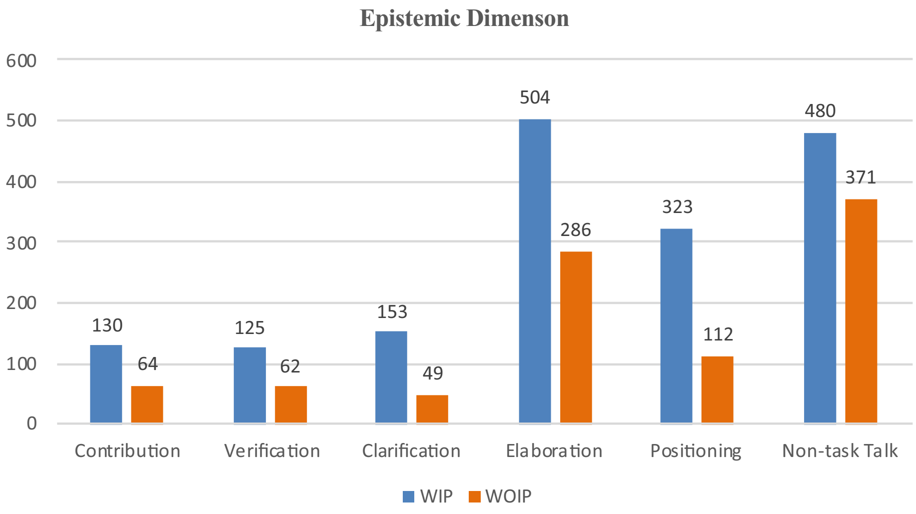

Fig. 1 Overview of the occurrences of statements in the epistemic processes

Table 6 Column proportions of the epistemic processes in the two experimental conditions

Epistemic processes	WIP (%)	WOIP (%)
Contribution	7.6[a]	6.8[a]
Verification	7.3[a]	6.6[a]
Clarification	8.9[a]	5.2[b]
Elaboration	29.4[a]	30.3[a]
Positioning	18.8[a]	11.9[b]
Non-task talk	28.0[a]	39.3[b]
Total	100.0	100.0

Note The column proportions test table assigns a superscript letter (a, b) to the categories of the column variable. If a pair of values is significantly different, the values have different superscript letters assigned to them

Differences between WIP and WOIP on the social processes

Similar to the epistemic dimension, there were also overall more occurrences of statements in all the five social modes of collaborative knowledge co-construction in the WIP condition as compared to the WOIP condition, in particular, in ‘integration-oriented’ and ‘conflict-oriented’ consensus building (see Fig. 2).

Chi-square test showed a significant difference in the social dimension between the WIP and WOIP groups (χ^2 (5) = 70.60, $p < 0.05$, Cramer’s V = 0.17).

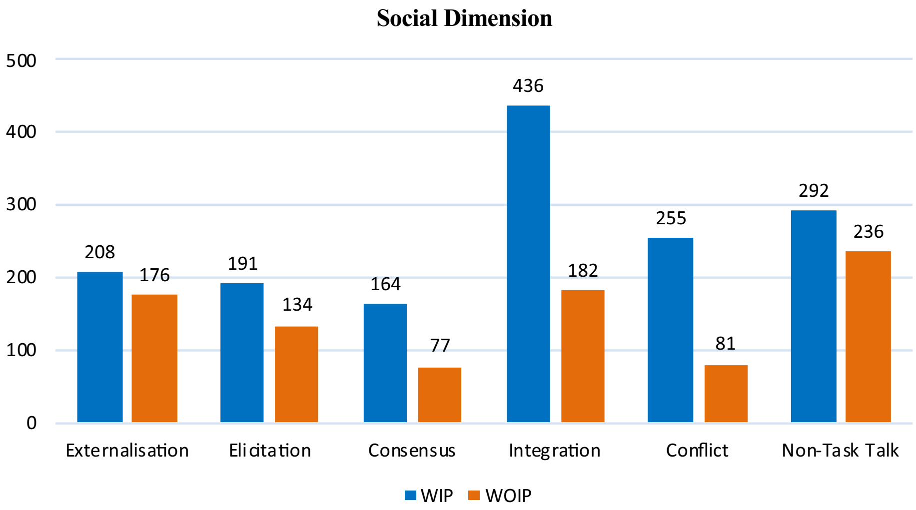

Fig. 2 Overview of the occurrences of statements in the social processes

Table 7 Column proportions of the social processes in the two experimental conditions

Social Processes	WIP (%)	WOIP (%)
Externalisation	13.5[a]	19.9[b]
Elicitation	12.4[a]	15.1[a]
Quick Consensus	10.6[a]	8.7[a]
Integration-oriented consensus	28.2[a]	20.5[b]
Conflict-oriented consensus	16.5[a]	9.1[b]
Non-task talk	18.9[a]	26.6[b]
Total	100.0	100.0

Note The column proportions test table assigns a superscript letter (a, b) to the categories of the column variable. If a pair of values is significantly different, the values have different superscript letters assigned to them

Table 7 shows the results of the z-test where the column proportions of the WIP and the WOIP groups are compared. This shows that there have been significantly more occurrences in the categories of 'integration-oriented' and 'conflict-oriented consensus' building, and significantly less in the 'externalisation' and 'non-task talk' in the WIP condition as compared to the WOIP condition.

Effects of WIP and WOIP on interdisciplinary knowledge integration in the CCM

Overall, descriptive statistics indicated that there were more concepts, domains, cross-links and types of cross-links for groups in the WIP condition as compared to the groups in the WOIP condition (see Table 8). It can be seen that the WIP groups has a higher mean value on all scoring variables as compared to the groups in the WOIP condition.

To investigate the degree of interdisciplinary knowledge integration in the CCMs, independent samples t-test was used to compare mean scores of the WIP and WOIP groups on all the four outcome variables (alpha level is 0.05). The Levene test indicated no violation

Table 8 Mean and SD of the CCM scores in WIP and WOIP experimental conditions

	WIP M *(SD)*	WOIP M *(SD)*
Concepts	48.75 *(24.92)*	22.50 *(14.11)*
Domains	7.50 *(4.80)*	5.50 *(3.51)*
Cross-links	11.50 *(4.73)*	6.50 *(2.87)*
Types of cross-links	4.00 *(.82)*	2.25 *(.96)*

of the assumption for equality of variance. There was no significant difference for concepts (t (6) = 1.83, p = 0.12), domains (t (6) = 0.67, p = 0.53) and cross-links (t (6) = 1.77, p = 0.13) between the two experimental conditions. However, there was significance in the types of cross-links (t (6) = 2.78, p = 0.03) with a large effect size ($\eta^2 = 0.16$) for the CCMs in the WIP condition. As for the structure of the CCM, there were no distinct differences between WIP and WOIP, almost all CCMs showed a hierarchical structure except for one CCM from the WOIP group which had a chain structure.

Discussion and conclusion

This research study investigates the effect of with- and without- an individual preparation phase (WIP & WOIP) on the epistemic and social processes, as well as the degree of knowledge integration in interdisciplinary collaborative concept mapping. Quantitative analyses on the epistemic processes in the two conditions indicated that students in the WIP condition showed significantly higher engagement in clarification, verification and positioning statements as compared to students in the WOIP condition. And in the social dimension, students in WIP condition demonstrated significantly more integration-oriented and conflict-oriented consensus statements that those in the WOIP condition. Taken together, epistemic activities such as verification, clarification and positioning statements are instrumental during the process of integration and conflict-oriented consensus building in the social modes of knowledge co-construction. In seeking clarification, verifying claims and questioning positioning of perspectives, students would have to pose questions, query assumptions and re-evaluate contributions and ideas. These findings showed that there was a higher degree of transactivity in the WIP condition where learning peers actively and meaningfully participate in each other's contributions during the collaborative task (though they had 30 min lesser collaborative work duration as compared to WOIP condition). More transactivity is associated with more knowledge integration (Wen et al. 2016) and a successful collaborative discourse in knowledge co-construction (Noroozi et al. 2013; Weinberger and Fischer 2006). Students in the WIP condition also displayed higher degree of knowledge integration in the interdisciplinary collaborative concept map, in particular, in the types of cross-links which we attributed to the significantly higher occurrences of integration-oriented and conflict-oriented consensus building statements.

For the groups in the WIP condition, the individual preparation phase could have provided the students an essential personal space to reflect on and to organize their thoughts and raw ideas. As evident in the findings, when the students in the WIP condition proceeded to work in their respective groups, they posed more question statements to seek verification and clarification at the collaborative level. This aligns with Gao's (2007) and van

Boxtel et al.'s (2002) findings that an individual preparation phase prior to collaborative concept mapping enabled the individuals to develop ideas and arguments more coherently and effectively at the collaborative level. In a similar fashion, Barron's (2003) study on "When Smart Groups Fail" also accentuate that the quality of the collaborative discourse, i.e., the interaction and the communication also carry significant bearings on the creation of shared problem space. Embedding an individual phase prior to collaborative work facilitates the process of achieving common ground in negotiating shared meaning and understanding (Tan 2018). Negotiating common ground in the shared problem space through posing relevant questions and argumentations could have facilitated higher level of transactivity in the interdisciplinary collaborative concept mapping process in the WIP condition. The study also contributes to the ongoing scholarly discussion on the dynamic interaction between group and individual cognition (Salomon 1997; Stahl 2006). It is problematic to attempt to understand shared group cognition without referring to the individual cognition: developing individual mental representations prior to constructing collaborative concept map is a necessary condition for building shared group cognition. This is even more pronounced in the context of epistemic and social processes in interdisciplinary knowledge integration. The results of this study indicate that it is desirable to develop mental representations through individual concept map before mental representations are shared in a collaborative concept map.

The WOIP condition exemplifies the theory of peer scaffolding (Collins et al. 1989; Rogoff 1990) which was evident in the descriptive data where there were higher occurrences of externalisation and elicitation of contributions and ideas, as compared to the groups in WIP condition. Peer scaffolding could have provided individuals at the collaborative level the necessary scaffold and transitory support during the knowledge co-construction process in collaborative concept mapping. On the same token, this transitory support by better students might have prevented disjointed and fragmented thinking (Senge 1990). However, it could have also unwittingly impeded socio-cognitive conflicts. Conflict is the source for cognitive growth and conceptual change (Levines et al. 1993). Conflict consensus building is the underlying mechanism in the social co-construction of knowledge (Weinberger and Fischer 2006). This could possibly explain the lower occurrences of integration-oriented and conflict-oriented consensus building statements in the WOIP group, and thus, the lack of transactivity in the interdisciplinary knowledge co-construction process where there were significantly fewer statements to seek verification and to question learning peers' positions in the epistemic dimension.

In sum, this study provides an insight into how an individual preparation phase prior to collaborative undertaking could better assimilate the individuals into the interdisciplinary collaborative knowledge co-construction: the individuals became cognitively and metacognitively more prepared during the negotiation of shared knowledge at the collective level.

Limitations and future work

We acknowledge that there are limitations in the attribution of effects in the two conditions (WIP & WOIP). One possible limitation and an area of contention could be the small sample size though an in-depth qualitative analysis of all collaborative discourse for the eight groups in the two conditions was carried out. Although the students were randomly assigned to the treatment and control conditions, there might still be some issues with the internal validity of the study such as the relatively small sample size and gender distribution with a low percentage of female participants. Jeong and Davidson-Shivers (2006) cited the high female-male ratio as one of the possible alternative explanations for the no significant difference between the two genders in computer-supported collaborative argumentation. Likewise, a study on argumentation skills found no significant differences within-gender/cross-gender difference for either female or male participants, however, a marginally significant difference in argumentation skills between male students in the within-gender team argumentation and male students in the cross-gender team argumentation (Hsu et al. 2018). Future research could include gender as a factor in the experimental setting.

The second limitation would be task complexity and cognitive load. We introduced the notion that managing cognitive load during the preparation phase of individual concept mapping could be beneficial for coping with collective cognitive load during the collaborative phase. In our study, some control on the complexity of the task and the size of the groups was provided. The instruction for constructing concept maps could have been instrumental for dealing with the cognitive load. Future work could explicitly explore the role of potential sources for extraneous cognitive load such as collaboration skills, team roles, team composition and prior team experience (Janssen and Kirschner 2020; Kirschner et al. 2018). It has also been found that members of teams often spent much more time in dealing with their individual cognitive style differences rather than working on the problem at hand (Jablokow et al. 2015; Kirton 2004). Further, an individual preparation phase without having to draft an individual concept map prior to the collaborative work phase could have different effect on knowledge construction and integration at the group level. This needs to be investigated.

A third limitation would be the integration of other disciplines whose cultural and social practices differ with changing collaborative learning contexts. For instance, the findings of our study seem to run contrary to the findings of Tsovaltzi et al.'s (2017) study where they reported negative effects of the individual preparation phase prior to argumentative knowledge co-construction. The reasons could be attributed to the different learning contexts and settings of the two studies. The study of Tsovaltzi et al. (2017) did not apply concept mapping. It was carried out utilizing an online social network application which could have induced self-centered behavior and self-presentation. On the same note, more research on different learning settings and with different age range and learners' prior knowledge is needed to affirm that embedding an individual preparation phase prior to collaborative work might be instrumental to enhance the epistemic and social processes in interdisciplinary collaborative concept mapping.

Notwithstanding the possible limitations, we believe that the findings of this empirical study provide useful insights on structuring collaboration and interdisciplinary knowledge co-construction. It showed that an individual preparation phase could possibly better assimilate learners into the collective work phase to establish common grounds and negotiate shared knowledge. The core findings could also inform the design and facilitation of interdisciplinary collaborative learning with or without concept mapping.

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