frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 21 April 2023
DOI 10.3389/feduc.2023.1108344

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Higher Education, a section of the journal Frontiers in Education

RECEIVED 25 November 2022
ACCEPTED 13 March 2023
PUBLISHED 21 April 2023

CITATION
van Lambalgen RM and de Vos F (2023) Facilitating epistemic fluency of undergraduate students during the interdisciplinary research process.
Front. Educ. 8:1108344.
doi: 10.3389/feduc.2023.1108344

Facilitating epistemic fluency of undergraduate students during the interdisciplinary research process

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Introduction: In this article we show how students share knowledge when integrating disciplinary insights in an interdisciplinary research project. More specifically, this research looks at how students communicate to create a shared mental model during moderated sessions with use of CoNavigator as an interdisciplinary collaboration tool or Miro as an online mind map tool. The study focuses on the interdisciplinary capstone of the Liberal Arts and Sciences bachelor program at Utrecht University (LAS), where students collaborate in multidisciplinary groups by going through the interdisciplinary research process (IRP).This process asks students to define an interdisciplinary research question, to define disciplinary insights and combine each other's disciplinary insights to create a more comprehensive understanding of their research question. The integration of disciplinary insights requires working with different perspectives and acknowledging uncertainty, thereby requiring epistemic fluency and higher modes of knowledge. This research looks at how a structured session with CoNavigator or Miro can help students use these processes when integrating insights.

Methods: Seven groups participated in this research, with whom we moderated a session using either CoNavigator or Miro at the start of the integration phase with the purpose of sharing disciplinary insights and finding common ground. We observed each group, looking at communication related to construction, constructive conflict and co-construction. In addition, we looked at evaluation of the tool immediately after the session and the assessment of the integration chapter of all groups.

Results: We found that each phase of the moderated session elicited different responses in terms of constructive conflict and co-construction, thereby helping students to actively work with different ways of knowing and to define and connect disciplinary differences. In their communication, students show examples of epistemic fluency and higher modes of knowledge, although this did not directly translate into a better assessment of their integration chapter.

Discussion: These results show that discussing disciplinary differences and finding common ground through a session with CoNavigator or Miro gives students a structured way to start with their interdisciplinary integration. We argue that LAS-students exhibit epistemic fluency when working with the tools, but also develop this throughout the session. It appears that the epistemic fluency students already possess prior to the IRP can be further developed by the epistemic fluency expressed by teammates during the tool session. The practice and development of epistemic fluency will always involve uncertainties, but facilitating interdisciplinary integration in this way is valuable as it provides an opportunity to work with these uncertainties and offer students space to speak and integrate freely.

KEYWORDS

knowledge integration, interdisciplinary research, tools, epistemic fluency, interdisciplinary collaboration, undergraduate education

1. Introduction

In this article we investigate how tools for interdisciplinary collaboration can facilitate disciplinary knowledge sharing in multidisciplinary student teams for the integration of disciplinary insights in an interdisciplinary research project. We look at how students share knowledge to create a shared team model and whether they show epistemic fluency (as defined by Markauskaite and Goodyear, 2017, p. 1). The study focuses on third year undergraduate students at Liberal Arts and Sciences, Utrecht University (LAS), who collaborate in multidisciplinary teams of 3–4 students for their interdisciplinary capstone and go through a version of the interdisciplinary research process (IRP) adapted from Repko and Szostak (2021, p. 75). This process consists of three phases in which they define the interdisciplinary research question (phase A), all students gather disciplinary insights from literature (phase B) and the team integrates their disciplinary insights to create a more comprehensive understanding of the interdisciplinary research question (phase C). This research focuses on the start of phase C: sharing and integrating disciplinary insights (Repko and Szostak, 2021, p. 75). Integration here is seen as combining different perspectives on an interdisciplinary problem with the means to advance understanding of this problem (Repko and Szostak, 2021, p. 222; Mansilla and Duraising, 2007, p. 225).

To integrate disciplinary insights, it is important that a shared team model is created such that all team members share the same knowledge (Van den Bossche et al., 2011, p. 288). This shared model can make it easier to communicate about finding common ground and to create a more comprehensive understanding of which every team member has shared ownership (Mathieu et al., 2000, p. 274; Lindvig et al., 2017). Van den Bossche et al. (2011, p. 296) conclude that for a shared team model to be created team members need to ask each other questions related to construction (sharing knowledge), constructive conflict (questions on differences and common ground in knowledge) and co-construction (communication to build on each other's knowledge). For interdisciplinary integration this means that students should be able to think about their own knowledge in relation to knowledge of others. Students have to rely on the higher modes of knowledge as defined by Savin-Baden (2014, p. 8), specifically Mode 3, 4 and 5 as they look for epistemological and methodological differences, address different pieces of knowledge and identify gaps between disciplinary insights in relation to the interdisciplinary research question. In Savin-Baden (2014, p. 8), Mode 3 knowledge means 'recognizing epistemological gaps', which is needed to identify differences between disciplinary perspectives and as such relates to both construction and constructive conflict. Construction is the first step to acknowledging that there are differences, where constructive conflict is needed to identify what differences there are. Mode 4 knowledge moves a step further as it allows students to reflect on 'disregarded knowledge' and 'different knowledge hierarchies' which are important elements when co-constructing a shared mental model: the identified conflicting insights are discussed in relation to each other, but also the students reflect on what the disciplinary insights do not address. Finally, Mode 5 knowledge 'holding diverse knowledges with uncertainty' (Savin-Baden, 2014, p. 8) can be seen as knowledge which allows students to map their conflicts and integrate them to define their relevance to the interdisciplinary research question.

These higher modes of knowledge involve uncertainty in their own way (Savin-Baden, 2014, p. 8): initial uncertainty about what the disciplinary insights are, how they interconnect, how they can best be combined to answer a research question and where the knowledge gaps are. It is beneficial for students engaging in interdisciplinary research to use these modes of knowledge and to express and develop epistemic fluency (Markauskaite and Goodyear, 2017). Epistemic fluency is closely related to skills in interdisciplinary collaboration as it involves "*A capacity that allows people to embrace and combine different kinds of knowledge and ways of knowing that are relevant to encountered tasks in a broad range of contexts*" (Trede et al., 2019, p. 179). In this context this involves the discovery of epistemological differences between disciplines, acknowledging different approaches to knowledge, but also the integration of these approaches to create common ground and a more comprehensive understanding that is relevant to all disciplines involved.

In this research, we have looked at how the tools CoNavigator (Lindvig et al., 2018; face-to-face tool) and Miro (online mind map tool) can be used to encourage knowledge sharing for interdisciplinary integration to create a shared team model and whether it facilitates epistemic fluency required from students to work with and reflect upon different ways of knowing. CoNavigator is a hands-on tool specifically designed for interdisciplinary collaboration with the purpose of facilitating creating a shared team model where all involved parties contribute equally (Lindvig et al., 2018). A session with the tool involves different phases of sharing and mapping knowledge, all guided by a moderator. Miro is an online tool, similar to a computer-based concept mapping tool that allows students to collaborate in an online environment (Simone et al., 2001, p. 278). A session with this tool can be moderated as well to encourage an honest and clear dialogue between disciplines. Through this dialogue both tools could facilitate epistemic fluency. The relation between epistemic fluency and dialogue in interdisciplinarity is explained by Colton et al., (2022, p. 524): "*Epistemic fluency can be enabled through the negotiating and dialoguing that occurs between individuals and between epistemic communities*." This negotiating relates to the communication that Van den Bossche et al. (2011, p. 288) refer to as being important for creating a shared team model. In this study, we looked at student communication when using the tool to see how students address different pieces of knowledge to create a shared team model, thereby looking at how these students express epistemic fluency.

We conducted this research in the context of the LAS capstone, aimed at LAS bachelor students. It is good to keep in mind that this is a group of students who are encouraged to develop epistemic fluency from the start of their bachelor program. For example, in the first

semester of the first year students follow an introductory writing course as part of the core interdisciplinary curriculum, aimed at teaching connective thinking, which is an important skill for doing interdisciplinary research (Haynes and Leonard, 2010, p. 662) and is also a relevant component of epistemic fluency. According to Trede et al. (2019, p. 180), one of the capabilities within epistemic fluency is "*To combine and integrate different ways of knowledge*," which is indeed what students at LAS learn in their core curriculum. Third-year undergraduate students (generally) have already completed three core courses in which they learned more about connective thinking, how to conduct multidisciplinary research and in which they gained some experience in interdisciplinary research. Throughout their curriculum these students encountered different moments where they communicated with other students from different disciplines, or where they had to learn insights and methods from different disciplines. A certain degree of epistemic fluency is therefore expected from the students we observed. Within the capstone they are challenged to further develop this skill.

To have a more in-depth view on knowledge sharing for the integration of disciplinary insights we looked at communication by three groups doing a CoNavigator session and four groups doing a Miro session. We specifically observed students sharing and integrating their disciplinary insights and the contribution of all students towards a shared team model. Doing this we investigated how the tools encourage the use of different modes of knowledge for the purpose of answering an interdisciplinary research question. In the method section we will explain more about our procedure of the sessions we held using the tool and about the coding scheme we used for our data collection and analysis of communication within the student groups. In the results section we will refer to different types of questions required to create a shared team model and how these questions allow us to measure epistemic fluency. Finally, we do not interpret epistemic fluency as an endpoint to be reached, but as a learning process in which students can continue to develop through practice in forming shared team models as part of interdisciplinary research.

2. Materials and methods

2.1. Participants

Our study is focused on third year undergraduate students at the bachelor program LAS, Utrecht University who participate in the LAS capstone to write their interdisciplinary thesis. For this, eight multidisciplinary groups are formed, consisting of three to four students with different disciplinary specializations. Therefore, our research involves a variety of student disciplines, ranging from Economics to Biology and from Philosophy to Cognitive and Digital Humanities (Table 1).

At LAS, UU the capstone is done over a period of 10 weeks and we recruited groups at the first meeting of the capstone. In the first period two groups volunteered to participate in a CoNavigator session and one group volunteered to function as a baseline measure (observation, no tool use). In the second period all groups volunteered to participate in a CoNavigator session, however because of Corona restrictions in the second period four CoNavigator sessions were transformed into online Miro sessions. Table 1 shows how the different groups were divided across the tools.

TABLE 1 Details of participating groups.

Group	Student's disciplinary specializations	Research topic
Baseline measure (no tool)	Conflict Studies, Social Psychology, Sustainable Science, Information Science	What possibilities are there to reduce the influence of disinformation about climate change in digital media?
CoNav-1 (pilot)	Economics, Anthropology, Conflict Studies, Philosophy	Is the promise of the blue zone characterized by universality or contingency?
CoNav-2 (pilot)	Dutch, Philosophy, Anthropology, Social Psychology	How can alternatives to essays as a form of knowledge transfer contribute to knowledge production within the university?
CoNav-3	Organizational science, Economics, Cognitive Neuropsychology	What role can nudging in making healthy eating choices play in tackling obesity in the Netherlands?
Miro-1	Philosophy, Cognitive Neuropsychology, Cognitive and Digital Humanities	How can the polarising effect of government communication on the COVID-19 vaccin program be reduced?
Miro-2	International Relations, Organizational Sciences, Social Sciences	To what extend is the Netherlands prepared for a Jihadic extremistic attack?
Miro-3	Organizational Sciences, Sociology, Social Sciences, Cognitive Neuropsychology	Why does a minority conforms to an anti-vaccination ideal during the COVID-19 pandemic
Miro-4	Social Sciences, Art and Cultural History, Biology	To what extent does the lack of sufficient progress achieved by AGRA explain food insecurity among the countries in which the project operates?

2.2. Procedure

We organized a session in which the student groups worked with either the hands-on tool CoNavigator (three groups) or the online tool Miro (four groups). The sessions were guided by a moderator (us as researchers) and took place at the start of phase C. CoNavigator is designed to create a shared topography, and we implemented a short session as described by Lindvig et al. (2018, see also: Lindvig et al., n.d.).

We adapted the sessions from Lindvig et al. (n.d.) to fit with the IRP. There is no general session length, but a whole session usually lasted at least 1.5 h. Students start by identifying the chosen theme for this session: in this case, this is the interdisciplinary research question that is central to their capstone. Then the team members are given the opportunity to write down for themselves which concepts/theories are considered important for answering this question, following from their own disciplinary perspective. Each concept/theory gets its own "tile." The students are then asked to make a 'shared topography' together, in which they arrange the different tiles based on, for instance, themes or epistemology. This is also the phase that generally took the most time but after 30 min we finished this phase. After this, the students individually flag the tiles they consider to be the most relevant for their shared research topic. This does not necessarily have to be a tile that they pay attention to in their own disciplinary part of the investigation. In the next phase, the students are given the opportunity to reflect on one of the tiles that received the most flags using a "zoom-in" technique. Each student writes on a new tile why they think the selected tile is essential for answering the research question. Each student is then given time to explain this. Then there is room for discussion about similarities and differences between the students' disciplinary insights and the noted concepts and theories. Where necessary, the selected tile can be rewritten so that it has a more comprehensive description of all insights combined. This process is repeated for multiple tiles, varying between one or three tiles. In the zoom-out phase, the team reflects on the shared map. The students are allowed to rearrange the map and also check whether there are still underexposed parts on the map that they would like to discuss. After this we look back at the session and think about how the insights gained during the session can be used in the further integration process as part of the capstone. The session ends with the capture of the shared map so that it can be referred to later.

In the online mind map tool Miro we did a similar session, having students create a shared map online. During the sessions we recorded communication between students and at the end of the session we had them evaluate the session. In this article we will focus on communication during tool use and evaluations immediately after where students reflected on the session. We also interviewed the teams at the end of their research process, focusing on how they used the tool to write their thesis. These results are presented in an earlier paper (van Lambalgen and de Vos, 2022). In the discussion we will briefly refer to these results, but we will not present them in this paper.

2.3. Measures

To measure the epistemic fluency that students show in their interdisciplinary integration we looked at how students share their disciplinary insights, address disciplinary differences and build upon these differences to connect to the interdisciplinary research question. For this we operationalized the concepts of construction (we make a distinction between positive and negative construction), constructive conflict and co-construction, as according to Van den Bossche et al. (2011) these components refer to what kind of communication is important to create a shared team model. For construction, we interpret positive construction as a visible aim of the team members to listen actively and to get a grip on contributions from group members. Negative construction is understood as a situation where team members show the opposite. Group members show confusion, do not actively listen to their group members or do not respond to each other. We defined observation codes by operationalizing these components to specific items and example questions based on the examples given by Van den Bossche et al. (2011) and adapted to fit with the IRP. Table 2 (2.1–2.3) shows how the different codes relate to the three components and what example questions fit with the codes. The table is used for observation of communication related to these codes, having example questions to clarify the different codes.

2.4. Data analysis

We have analyzed the scores in the observation tables during different phases of the sessions, focusing on the mapping phase, the zoom-in phase and the zoom-out phase, because that is where most conversation happened. We have looked at the average and standard deviation of observations across all groups, either using CoNavigator or Miro, because the number of groups using each tool was too low to be addressed separately. In the results chapter we also give examples of the different observations within construction, constructive conflict and co-construction which are necessary to create a shared team model. In addition, we have looked at how students evaluated the tools in terms of construction, constructive conflict and co-construction in the evaluation immediately after a session (in case of CoNav-1 and CoNav-2 we did not take the evaluation as these were pilot sessions). These results together explain how students express different components of epistemic fluency: openness to each other's discipline, addressing disciplinary differences and connecting disciplinary perspectives.

3. Results

In this section the results are presented of observations of four Miro and three CoNavigator sessions and of interviews immediately after the sessions (four Miro and one CoNavigator session). As stated, we relate the results to the different components of construction, constructive conflict and co-construction and we will reflect upon the relationship of the results to epistemic fluency and show how the results relate to the different modes of knowledge.

In general students were happy to participate in the sessions and showed positive evaluations afterwards, both in Miro as in CoNavigator. Responses showed that the sessions provided a certain amount of calmness at the start of the integration process of the students:

CoNav-2.2: "It brings me peace of mind. I can see that we relate more to each other then I originally thought."

Miro-3.1: "The easeful feeling that we, well it felt as though we were going in the right direction, that we knew in which direction we were going and that we were going the right way."

We found it was difficult to compare both tools because groups were at different points in their integration with different knowledge about their disciplinary insights (i.e., some groups already shared their disciplinary insights in an earlier meeting). In addition, the IRP is often dependent on characteristics of the group members and the interaction between group members at the time. For example, we used

TABLE 2 Items and examples of observation constructs.

2.1. Construction	
Item	Example
Student explains concept	• "In my discipline this means…" • "I think this is…" • "What I mean by this…"
Concepts of group members are considered relevant	• "This is not an issue in my discipline, but it is interesting for us to think about"
Joint focus of attention	• Altogether: "Yes" • "Then we found what we were looking for"
Open questions are asked	• "How do you interpret that with your discipline? What do you think is the difference between our disciplines? So what does your discipline say about effectiveness?"
Students show active listening communication	• "Ok" • "Hmhm" • "Yes, exactly…"
Students do not understand the explanation of group member X	• "What do you mean by…?" • "I do not understand what you mean by…" • "Huh?"
Students explicitly go on about something else after an explanation or are not actively listening to each other	• "Yes but it is about something else" • "I actually do not think we need to pay attention to this" • Or - > The students ignore what has been said
2.2. Constructive conflict	
Item	Example
"Team members address differences in opinion"	• "I see this is your insight and I think it is different from what I have seen"
"[…] dealing with differences in interpretation."	• "Yes, but you are talking about the same thing, because…" • "What we can learn from this difference in interpretation is…"
"Negotiation of meaning"	• "I think it means this, you say it means this, is it not just both?"
Critical questions are asked	• "But why does your discipline say that?"
"Open-minded discussion"	• At group level
Something is done with the comments on ideas/criticisms are acknowledged	• "Oh maybe I could phrase that in a different way" • "Perhaps we indeed need more than what my discipline supposes"
Differences are viewed and employed as an opportunity rather than seen as a threat to progress	• "It is a good thing that these disciplines result in different insights, because it offers us a deeper understanding of our issue"
2.3. Co-construction	
Item	Example
Team members supplement information with new information	• "Is this what follows from your discipline? From my discipline it follows…"
Team members build on each other's information, make connections at a higher level	• "So you are talking about conditions and I am talking about action" • "We could make a new concept out of this" • "We can use your idea to"
Team members draw conclusions/summarize	• "So that means this discipline…" • "We can conclude that…" • "In short…" • "So eventually…"
There is mutual agreement/mutual agreement is confirmed by the whole group	• "Do we agree that…?" • A level higher than concluding, summarizing. Transcending shared understanding is reached
An active effort to integrate the contribution in the existing representation	• "If we want to include this in its entirety, we can bring that together" • "And what do we want to do with these tiles?" • Zoom-in/zoom-out
Suggestion for mapping	• "We could first place political concepts together, e.g., government"

TABLE 3 Average observations per item on construction.

Item	Mapping	Zoom-in	Zoom-out
Student explains concept	M = 6.3 SD = 2.6	M = 10.6 SD = 3.8	M = 4.4 SD = 3.2
Concepts of group members are considered relevant	M = 0.6 SD = 0.73	M = 2.6 SD = 4.1	M = 1 SD = 2.1
Joint focus of attention	M = 1.1 SD = 1.2	M = 0.6 SD = 0.73	M = 0 SD = 0
Open questions are asked	M = 10.9 SD = 5.9	M = 5.9 SD = 6.5	M = 1.86 SD = 1.81
Students show active listening communication	M = 3.3 SD = 3.7	M = 1.9 SD = 1.9	M = 1.3 SD = 1.4
Students do not understand the explanation of group member X	M = 0.4 SD = 0.73	M = 0.7 SD = 1	M = 0 SD = 0
Students explicitly go on about something else after an explanation or are not actively listening to each other	M = 0 SD = 0	M = 0 SD = 0	M = 0.1 SD = 0.4

the baseline session for comparison with a meeting without a tool, but this seemed to be a group that was functioning relatively well, having scheduled multiple collaborative meetings. What we did observe during the sessions was that the contribution across team members was more equally divided across members in a CoNavigator session as compared to the Miro sessions and the baseline session. In the baseline session there was someone leading the session to bring structure in their meeting, and in the Miro sessions there was often one person who seemed to communicate less. In addition, working with Miro did provide the additional challenge of having to work with computers, to which not everyone was adept, as was the case with Miro-3.3, who said: "I really find it so hard, those online things."

3.1. Construction

Looking at the operationalization of construction in Table 2 (2.1), construction is a prerequisite for the later phases, meaning that it is important that students actively listen to each other, are open to each other's information and ask questions if they do not understand the insights. As pointed out in the introduction, the ability to construct can be seen as a starting point for mode 3 knowledge: the acknowledgement that there are other disciplinary views and the idea that those are valuable and should be recognized before actually knowing what the exact differences are.

During the whole session and across the two types of sessions all groups showed elements of openness in their conversation. Table 3 shows the average numbers of each concept related to construction. We did not observe much negative construction: the average of cases where students do not understand the explanation of a team member or actively go on onto something else ranged from 0 to 0.4. In terms of active listening as observing "ok" or "hmm," the average is relatively low as can be seen in Table 3. It should be noted that this does not mean that students did not listen to each other actively, but they may not have been expressing it as such. In contrast, 'asking each other questions' had the highest average of 10.9 during the mapping phase and 'student explains concept' was highest during the zoom-in phase ($M = 10.6$; $SD = 3.8$). These results are aligned with the specific phases of the sessions: during the zoom-in phase students are explicitly asked to explain their disciplinary definition of a specific concept, guidance that is not there during the mapping phase. During the mapping phase students are prompted to ask each other questions about the disciplinary concepts on the map. This shows that the tools indeed contribute to students acknowledging and valuing each other's disciplinary views, thereby setting the conditions for epistemic fluency and the ability to evaluate differences between disciplines, connecting to mode 3 knowledge.

Table 3 shows a high standard deviation across all elements of construction, indicating high variety between groups. For example, there were two groups who did not ask each other many questions, even though they were encouraged to do so: two groups working with Miro asked each other only 1 and 4 questions during the mapping phase. These groups were also the groups that already had an earlier brainstorm session in which they shared each other's disciplinary insights. However, it could also be a result of working online with Miro as opposed to working face-to-face with CoNavigator: all groups working with Miro reflected during the evaluation of the session on their hesitance to keep communicating online. As an example, Miro-3 said:

Miro-3.3: "You feel less responsible to answer, while, yeah someone literally asks you something, but through the laptop it may feel as though it is not for you to answer."

Miro-3.2: "Hmm, I think (Miro-3.3: Yes…) that maybe the pressure is even lower because you are still safe behind your laptop or something (Miro-3.3:Yes), that it feels like less pressure to talk."

And in Miro-4 students also reflect upon the timeliness of responding:

Miro-4.1: "It takes much more time: you cannot just say something because you have to wait for each other. And you cannot talk at the same time."

Looking at the overall results on construction, students show that they acknowledge each other's disciplinary views on their research question. This is elicited by the tools as students are encouraged to ask open questions in the mapping phase, and to listen to each other's disciplinary explanations in the zoom-in phase. It may also come forth from their interdisciplinary curriculum. From the first semester in the first year of LAS they learn to be open towards different perspectives and to look for connections between different views. In the course on interdisciplinary research in their second year, students talk to each other about their disciplinary insights and learn to integrate different perspectives. In terms of epistemological fluency, this means that they are used to "engage with different ways of knowing the world." This fits with the quality of perspective taking that is important when doing interdisciplinary research (Repko and Szostak, 2021) and which these students learn as part of their LAS interdisciplinary curriculum.

3.2. Constructive conflict

In this section we will describe how students communicated in terms of constructive conflict when using the tools, relating to Mode

TABLE 4 Average observations per item on constructive conflict.

Item	Mapping	Zoom-in	Zoom-out
Addressing differences	M = 0.7 SD = 0.7	M = 2.2 SD = 1.6	M = 1 SD = 0
Dealing with differences	M = 0.7 SD = 1.7	M = 2 SD = 1.5	M = 1 SD = 0 Max = 1
Negotiation of meaning	M = 1.71 SD = 1.9	M = 1.3 SD = 1.4	M = 0.3 SD = 0.75
Critical questions	M = 2.7 SD = 3	M = 1.4 SD = 1.8	M = 0.28 SD = 0.7
Acknowledging comments	M = 2 SD = 1.7	M = 2.14 SD = 2.99	M = 0.86 SD = 1.5
Differences as opportunity	M = 0.57 SD = 0.72	M = 2.4 SD = 1.28	M = 0.57 SD = 0.9

3 knowledge: recognizing epistemological gaps, as described in the introduction. Table 4 shows the average of the specific elements in the different phases and it can be seen that the overall number of observations is low as compared to construction and co-construction. During the mapping phase, most observations came from the elements of 'asking each other critical questions' and 'acknowledging comments'. There were a few instances during this phase on 'negotiation of meaning', but little communication about differences ('addressing differences', 'dealing with differences' and 'seeing differences as an opportunity') during this phase. During the zoom-in phase there was more focus on the differences in terms of 'seeing differences as an opportunity', 'addressing differences' and 'dealing with differences', no element was specifically low during this phase. During the zoom-out phase most elements were equal to or below 1.

As shown by the average number of observations, we found that the zoom-in phase of the tool encouraged conversations about epistemological differences and that after the students explained their disciplinary point of view students indeed reflected upon the differences between the different insights. This discussion is the beginning of the transition from mode 3 to mode 4, because group reflection forms the basis for pointing out important differences, which should eventually lead to a hierarchy. This activity was partly elicited by us as moderators as we asked students to reflect on these differences. A good example of such a conversation during the session is found in team CoNav-3, where CoNav-3.3 is discussing their approach to nudging:

CoNav-3.3: "In my discipline, I investigate how people make decisions, and I focus specifically on how nudging works for the individual, the consumer actually. So, in that regard, CoNav-3.2 and CoNav-3.1 seem to identify a black box by stating: 'yes, nudging, it is a great system, but how does it actually work?' and they focus on applying nudging. So, I sort of explain what it actually is and then they go into more detail about how we can actually apply it. Because it is nice to know how it works, but if you do not know how to apply it, it is also quite difficult. So yes, for me it is a phenomenon and for them it is a tool."

Here, CoNav-3.3 explicitly discusses that the different disciplines have different approaches to nudging. In this the student reflects on the approach of their own discipline ('I investigate how people make decisions'), and the insights that coincide with that approach. The student then shows how other disciplinary views are different and how it is possible to integrate the views. By this, the students show that there are knowledge gaps in their own discipline (Mode 3) and also that there might be diverse knowledges which all have their own uncertainty (Mode 5; Savin-Baden, 2014, p. 8).

Similar conversations can be found by groups that use Miro as a tool, such as Miro-4 here, who talks about the interaction between history and sociology.

Miro-4.1: "But the starting point is different. When you look at historians, they have a more objective view on policy and knowledge on the context of power relations, instead of talking about the direct consequences for the societal context."

Miro-4.2: "Yes, that is indeed true. I think this could be a conflict, always when it relates to government policy I do not have anything to add to the content, in general what I have to say is not relevant. And that is a bit contradictory: If it was government policy of 100 years ago, it would have been really relevant."

Miro-4.1: "Maybe there is an epistemological difference. It is about approaching knowledge and truth. It is not necessarily an assumption, it is more about how do I develop knowledge and science."

Miro-4.2: "Maybe it is also about how you see the relation between what happens in a country and government policy. Maybe if we would draw it schematically, we would define a different relationship, that the order should be different?"

In this conversation they are talking about their different disciplinary views, they reflect on the origin of the difference and thereby also relate to the epistemology of the discipline. Here they show epistemic fluency in terms of Mode 3 knowledge: identifying epistemological gaps. In the last remark, Miro-4.2 is not necessarily building upon the remark of Miro-4.1, but together they do aim to figure out what the differences between history and sociology are and how they are in relation to each other. Note that this is mainly a conversation between two of the three students, the third student was less active throughout the whole session.

The following example gives an example where communication shows that students are figuring out the purpose of the different disciplines. In this discussion you can see that Miro-2.1 is really trying to explain the historical perspective towards government policy.

Miro-2.3: "So you look at it from a historical perspective?"

Miro-2.1: "Yes, because I am a historian."

Miro-2.3: "I think with Miro-2.2 you really see that it is about how you bring policy in practice. And with Miro-2.1: I do not necessarily understand why you say that political parties come from the past?

Miro-2.2: "I think this is a big difference indeed, that Miro-2.1 is writing from a historical perspective and we do not."

Miro-2.1: "Yes, this sounds really dumb, but where do you think ideas of politics come from?"

Miro-2.3: "Did that not that change then?"

This example shows that by talking to each other students figure out what the historical perspective entails and how this perspective looks at political ideas. In this case, the students have conflicting insights in terms of where political ideas are from but at this point find it difficult to use this conflict and apply it to their interdisciplinary research. This is contrary to the communication of group Miro-1, in which a team member recapitulates the contribution of another team member by turning it into the description of a conflict:

Miro-1.1: "Well I see right away what, Miro-1.2, what you say about linguistics and psychology actually. That I have used hierarchy

TABLE 5 Average instances of items related to co-construction.

Item	Mapping	Zoom-in	Zoom-out
Team members supplement information with new information	M = 1.3 SD = 1.3	M = 4.9 SD = 4.2	M = 0.6 SD = 0.7
Team members build on each other's information, make connections at a higher level	M = 2.3 SD = 2.4	M = 5.7 SD = 4.2	M = 1 SD = 1.3
Team members draw conclusions/ summarize	M = 2.6 SD = 2.9	M = 2.6 SD = 2.6	M = 2.7 SD = 3.8
There is mutual agreement/mutual agreement is confirmed by the whole group	M = 1.9 SD = 1.9	M = 0.3 SD = 0.5	M = 1.6 SD = 1.4
An active effort to integrate the contribution in the existing representation	M = 6.6 SD = 6.8	M = 2 SD = 1.4	M = 3.3 SD = 4.3
Suggestion for mapping	M = 9.9 SD = 7.5	M = 1.9 SD = 2.2	M = 1.4 SD = 0.7

so that it mainly assumes that it is inherent in language (Miro-1.2: Yes) that you cannot do much about it. And I was just talking about psycholinguistics, that can do something with that (Miro-1.2: Yes). It says that hierarchy can be expressed (Miro-1.2: Yes) with the help of language, but perhaps it can also be hidden or something (Miro-1.2: Hmhm).

[…]

Miro-1.2: "[…] that is actually kind of a main conflict between your two disciplines that we have talked about before (Miro-1.1: Yes). Kind of, is language the means or the origin?"

Here, the group demonstrates its ability to identify a conflict and then initiate an understanding of the usefulness of conflict, to emphasize the value of this conflict for answering the research question. By this, students show mode 5 knowledge as they hold diverse knowledges and aim to apply these in an uncertain context. This brings the students to the next step in their integration process: co-construction. Students recognize when they can convert conflict into valuable insights, illustrating their epistemic fluency.

3.3. Co-construction

For the topic of co-construction we have looked at instances of contributing to the existing representation, to which we also relate proposals about mapping a specific situation and making connections between each other's disciplinary insights. We found that in all groups students were in one way or the other actively working towards the integration of their knowledge. Table 5 shows the average and standard deviation of the observations across all groups and in the three different phases. SD is relatively high in most cases, displaying a large variation between the groups, both the Miro and CoNavigator groups. Overall students showed multiple instances of co-construction in all different phases, but mainly in the mapping and the zoom-in phase, also because teams spent more time in these phases.

A high average of observations was found for 'an active effort to integrate the contribution in the existing representation' and 'suggestions for mapping' during the mapping phase, resonating with the purpose of this phase: to map insights and to talk to each other to create a combined visualization of their disciplinary insights. An example of such a suggestion for mapping was found in CoNav-3:

CoNav-3.2: "Yes, and then you could put manipulation near ethics."

It should be noted that this mapping did not necessarily include conversations about the meaning of the disciplinary insights, which might indicate that it included individual contributions to integration as opposed to a shared team process. There was a low average number of observations during this phase for the elements: 'supplement information with new information', 'make connections at a higher level' and 'confirmed mutual agreement'.

During the zoom-in phase, students were less active in mapping their insights and were working less on the existing representation as there were fewer average observations (see Table 4) for the elements of 'mutual agreement', 'active effort to integrate the contribution in the existing representation' and 'suggestions for mapping'. In this phase, teams showed most co-construction related to: 'supplement information with new information' and 'build on each other's information, make connections at a higher level'. Zooming in on a specific concept may indeed facilitate mode 4 knowledge: students discuss epistemological differences and discuss them in relation to each other. More specifically, during this phase students listen to each other's disciplinary view on a concept and then relate this view to their own view, actively connecting pieces of information. The tools facilitated this in that they visualized the disciplinary differences and we as moderators encouraged students to reflect on these differences by asking them to see whether they could see conflicts or ideas for common ground. After this, often one of the students first would propose a common ground or an integration of these different disciplinary views relating them to the interdisciplinary research question. This was also the case in the example of Miro-2 where they talked about the topic of institutions:

Miro-2.3: "I think I am relatively close to Miro-2.2 in this regard: institutions are not only companies, but also norms and values in the society, I believe this coincides."

Miro-2.1: "I wrote down that institutions are organizations such as governments and companies. I think it is relevant because institutions are influential."

Miro-2.2: "I think this shows the difference between top-down and bottom-up. Miro-2.3 and I see institutions as norms and values on top of organizations, for Miro-2.1 institutions really mean established organizations with a specific right to exist."

This conversation shows that students first talk about their differences between disciplinary insights and then place them on different levels (top-down and bottom-up), thereby creating a new understanding of the concept institutions. In this example they do not explicitly look at the epistemological differences as they do not address the origin of these disciplinary differences or relate them to

disciplinary epistemology and method, but they do aim to bring together the disciplinary perspectives. By this, they show that they recognize that there are different knowledge contributions and that their own discipline is not the sole answer (Mode 3). In addition, they actively explore structures and beliefs as is important in knowledge Mode 5 (Savin-Baden, 2014, p. 8).

Comparing the structure of such conversations to the IRP, the latter focuses more on identifying conflicting insights and their sources (Repko and Szostak, 2021). In the IRP, the common ground techniques follow from the origin of disciplinary differences. In the case of our research, both tools encouraged groups to look for a way to combine the perspectives to contribute to the interdisciplinary research question. This meant that during the sessions the groups placed less emphasis on the source of conflicting insights. What we saw when observing the baseline group (working without a tool) is that they talked a lot about the meaning of the specific integration techniques, thereby sometimes forgetting the purpose of their research: answering the interdisciplinary research question. We observed that the tools facilitate students to look further then their insights and also relate these to practice, coinciding with knowledge Mode 5 (Savin-Baden, 2014, p. 8). The following conversation by Miro-4 on food systems in Africa is a good example of this:

Miro-4.2: "We can add to each other's insights. If you see them next to each other, I think you can connect them quite well."

Miro-4.1: "Yes, the one seems to introduce the other. Colonialism as a concept caused specific power relations. This influenced the current policy, has directed the current policy. And this directed who has what and who decides and how they operate in their agriculture."

Miro-4 is actively working towards connecting different disciplinary insights, by looking at how knowledge connects and looking at a shared horizon between the insights, even defining a concept (overgeneralization). These students address knowledge to add to their integrated model and apply Mode 5 knowledge as they work with the uncertain outcome of the interdisciplinary integration. You see that in this set-up there is one student who acknowledges the connection, giving opportunity for the others to build on this. By defining such a connection, students show that they can look at the bigger picture and are encouraged to think towards the answer to the interdisciplinary question. In this, the zoom-in phase was helpful to start the conversation on disciplinary differences, but students themselves acknowledge the different perspectives, and relate those perspectives to their interdisciplinary research question. This was also pointed out in the evaluation, mainly after use of CoNavigator: the tool helped them not only to look at differences but also to apply common ground with the specific purpose of answering a research question. On this, CoNav-3.1 says:

CoNav-3.1: "Yes, well we did have quite a lot of conflicts, we had them already before we came here, so I do think after today we can approach the MCU, with all the things that we found, with all the differences we can combine to a specific conclusion of our overall research."

CoNav-3.2: "Yes, I agree with what CoNav-3.1 is saying. Because we were busy looking at: "well, what is different?" but not so much with "oh, how do we have to answer our research question?." And because the research question was quite central in tool use like: "what do you think is important for the research question?" or to see it as answering the research question, I think that became clearer now."

TABLE 6 Assessment of the integration chapter (scale of 1–10).

Group	Grade of the integration chapter
Baseline measure (no tool)	6.5
CoNav-1 (pilot)	7.5
CoNav-2 (pilot)	Insufficient, 7.5 after retake
CoNav-3	6.6
Miro-1	8
Miro-2	6
Miro-3	Insufficient, 6 after retake
Miro-4	8.3

The goal-directedness of doing such a session is valued by other groups as well, as is stressed by what Miro-4.3 says during the evaluation:

Miro-4.3: "I found it very useful, because first, you are being goal-directed with the bigger research picture in mind. Instead of looking specifically to similarities. Therefore you have more knowledge on the relevance of your conflicts and similarities. They are also important themes that you investigate, instead of it being irrelevant concepts you happen to come across."

This shows that the tools can indeed facilitate epistemic fluency: applying knowledge and extending it towards a broader context, in this case the more comprehensive understanding of the interdisciplinary research question (Markauskaite and Goodyear, 2017, p. 107). Then during the zoom-out phase, students again show they apply their integrated knowledge to the existing representation: the average number of observations was highest for 'an active effort to integrate the contribution in the existing representation' and 'team members draw conclusions'. There is less new information, but students work towards the overall integration during this phase.

3.4. Interdisciplinary integration

When looking at the assessment of the integration chapters, we found a variation in grades (Table 6) seemingly independent on the use of either of the tools for sharing disciplinary insights. Although the grade can also be dependent on factors outside the scope of this research, such as the specific supervisor and the collaboration within the groups, in this section we reflect on potential explanations for the variability in grades in terms of epistemic fluency.

Firstly, there are still steps required from the output of the tool session to writing the integration chapter: the assessment of the integration is dependent on how the students write down their insights and how well they describe the steps of the IRP. For their integration chapter they have to summarize their disciplinary insights, describe the conflicts between insights and create common ground before describing the more comprehensive understanding of their interdisciplinary research question. During the sessions we did see that students came up with relevant conflicting insights and that they were able to integrate their perspectives to add to the interdisciplinary research question. For a number of groups these conflicts did lead to relevant concepts such as overgeneralization for group Miro-4 and institutions for Miro-2. However, there is high variability in how the groups describe the conflicts and how they create common ground

from there. Groups that do this well get higher grades, as is the case with Miro-4 whose assessor said that they were proficient in handling the interdisciplinary method and had a good understanding of their research project.

Secondly, the students showed epistemic fluency throughout the session, but some students were more active than others. For creating the common ground it is important that all students apply higher modes of knowledge, because otherwise important perspectives can be missing. This can be seen in the assessment of Miro-2, where the assessors state that they miss the perspective of one of the disciplines in the more comprehensive understanding. This was less the case with the groups with a higher grade. This shows the importance of a shared epistemic fluency versus individual epistemic fluency: if all team members use their higher modes of knowledge they all contribute to a balanced integration of insights.

4. Discussion

Through the analysis of the conversations we have shown how students construct a shared mental model through a moderated session with CoNavigator or Miro when participating in the IRP. By mapping how their disciplinary insights together relate to their interdisciplinary research question students are actively translating their separate disciplinary insights to each other and are working towards the integration of these insights. Here, they apply the higher modes of knowledge, dealing with uncertainty of what the integration of disciplinary insights should look like and they show that they are able to work with different disciplinary methodologies and epistemologies. The tool provides a structured way to have them communicate about their disciplinary differences and similarities and encourages them to define a common ground between the disciplines and to relate this to the interdisciplinary research question. In this research we could not translate the outcome of the tool sessions directly to the assessment of the integration chapter in the thesis. We did see that students used their conclusions from the sessions in the integration chapter, but the assessment of this chapter varied highly between groups. What we found from our earlier analysis of the interviews with the groups after they finished writing their interdisciplinary thesis is that students feel the tool gives them a good start with their interdisciplinary integration and they feel they have more shared knowledge on the problem (van Lambalgen and de Vos, 2022, p. 215). However, students also indicate they need more help with how to use this knowledge after the session, which might explain the difference in assessment between groups.

These results show how the students have already developed a certain degree of epistemic fluency by completing their undergraduate program up to this point. This resonates with findings from van der Lecq (2016, p. 92–95) who showed that in their final reflective essays LAS-students show cognitive maturity by acknowledging the value of multiple disciplinary perspectives, by exhibiting different ways of knowing and by the application of interdisciplinary skills in other contexts. A similar interdisciplinary journey of undergraduate students in an interdisciplinary curriculum is shown by Haynes and Leonard (2010, p. 662). In our observations this has mainly manifested itself in the ability to be open and flexible towards disciplinary insights of others, to articulate one's own interdisciplinary insights and to understand and build on the disciplinary insights of others. LAS students are able to implement their skill of connective thinking in their research project, which includes the ability to see differences and similarities between different ideas (Sill, 1996, p. 146).

It is valuable to point out that epistemic fluency is not a stationary target but a process and the use of the tools ensures that this process does not end with the capacity for epistemic fluency that the students have already acquired. Using the tool not only gives the students the space to show the epistemic fluency they already possess, but it also gives them the opportunity to develop it further. The results illustrate how the steps in the use of tools provide a learning environment in which the members of the student team are all given the chance to contribute. Students are explicitly asked to communicate with each other at higher levels of knowledge, which contributes to the practice of epistemic fluency as a skill. In this situation, the students also get the opportunity to learn from each other how you can use this skill in working towards an integration of insights through a shared mental model towards ultimately answering their interdisciplinary research question.

Our observations address the importance of distinguishing between individual epistemic fluency and group epistemic fluency. On the individual level, epistemic fluency can be understood as when a student reflects on the origin of the disciplinary differences and thereby contributes to the group shared mental model. Individual students have not only mastered epistemic fluency on the base level they are already expected to possess as LAS-students, they also, to a certain extent, mastered epistemic fluency as a skill to the extent that it is valuable in the tool structured integration phase. They show that they can help each other to reach higher levels, as there are differences in the capacity of epistemic fluency between individual students. If a student with a higher level of epistemic fluency contributes to the group discussion that collectively brings the group to a higher level of knowledge, then the others can piggyback on that level. Students have the potential to create a shared epistemic fluency: by being open to each other's insights and by adding to each other's ideas of integration, the team together has knowledge on how their combination of disciplines contributes to the interdisciplinary problem. It should be noted that this does not always happen as such, resulting in differences in shared knowledge between students, which is potentially what caused the differences in the integration output and assessment thereof.

We see value in this tool for educational practice: the step of integrating insights is often seen as a hurdle and entails uncertainties (van Lambalgen and de Vos, 2022, p. 213). The tools can help to provide guidance, to support them in their problem-solving capabilities. Because we do not see epistemic fluency as an end point, but as a continuous development process, the practice and development of epistemic fluency will always involve uncertainties, but the tools provide the optimal conditions for this development. The tools are valuable as they provide an opportunity to work with these uncertainties and offer the students space to speak and integrate freely. In this, the tiles may work as boundary objects, an object that is open to different interpretations (Star and Griesemer, 1989; Luna-Reyes et al., 2019, p. 497). Tool use facilitates students to use higher modes of knowledge and thus gives potential for the formation of shared epistemic fluency among the group members. Whether this potential is fulfilled depends on how the students themselves translate the tool use into their research process.

Although in this research we did not find specific differences in epistemic fluency between the use of the two tools Miro and CoNavigator, it is important to recognize there are potential differences in use of these tools, mainly seen in the differences in overall communication online and face-to-face: online it is easier to keep quiet, which means ideas may be left unsaid and it may be unclear if there is a joint focus of attention. This can be seen in literature on online and face-to-face education as well: online education influences non-verbal communication thereby effecting the social presence during communication (Kreijns et al., 2014, p. 11; Zhan and Mei, 2013, p. 132). In addition, it is more difficult to interrupt each other online which may discourage students to build upon each other's insights. To encourage the learning process online as well it means that there is an additional role for the moderator to actively encourage students to share their findings and to identify their joint focus of attention.

This research contributes to the research field of epistemic fluency by investigating the practical exercise and development of epistemic fluency among a student population within the context of interdisciplinary university education in which students work together in teams. This practical approach to epistemic fluency shows that tool use can contribute to this development to a certain extent. Also, this research is unique amongst the literature on interdisciplinary education as often, research about interdisciplinary integration describes the importance of integration (Carmichael, 2014, p. 53) or discusses how interdisciplinary courses teach integration (Klaassen, 2018, p. 846). Newell et al. (2006, p. 92) do look at how undergraduates integrate different disciplinary insights, but only at an individual level. This research provides an analysis of how students communicate when integrating disciplinary insights, resulting in insights on knowledge sharing and knowledge creation in multidisciplinary student-teams. Finally, our research provides insights into the interpretation of epistemic fluency as a concept. It has made us realize that there is a need to approach epistemic fluency as a process rather than a stationary target, distinguishing between individual epistemic fluency and shared epistemic fluency, which must also be taken into account when deploying the tools. Our research results provide several perspectives for further research into the exercise and development of (shared) epistemic fluency among student populations within interdisciplinary contexts. It also offers a starting point for further deepening of epistemic fluency as a scientific educational concept.

4.1. Limitations and further research

In what follows, we discuss the limitations we have encountered in our research, and then point out potential points for further research.

In terms of conducting and analyzing our research: we have compiled a list of items with care and in a joint manner and together have defined the examples from earlier experiences with interdisciplinary research supervision. We divided the groups for observation of communication, so personal differences may have resulted in different observations per group. In addition, it proved to be difficult to have a statistical comparison between observations in the groups for two reasons: firstly groups can vary largely in characteristics of the individual group members and in their previous interactions and secondly the length of the sessions varied between the groups. We do think that in spite of these issues, the observations give us a good overview of what is said during the sessions and that through the qualitative comments we were able to analyze how the sessions enabled communication within the teams. We realize that the number of student groups we have studied is limited and that researching on a larger scale might have provided new insights. The distribution of the groups (the number of Miro groups versus CoNavigator groups was unequal and two of the three CoNavigator groups were pilot groups), was not ideal, which made it difficult to compare across groups. Follow-up research could be based on repeating this study among other student groups, also to see how different features of student groups interact with tool use.

In the current research, we as researchers acted as the moderators of the sessions and were not involved in the supervision of the groups. In future research we could look into other options of moderating such sessions in the exercise and enrichment of epistemic fluency by students during the tool sessions. It would be relevant to look at how a supervisor can moderate such sessions. In our teaching practice, CoNavigator is now actually implemented in the LAS capstone with sessions that are moderated by the thesis supervisors. The supervisors are prepared for this task by going through a CoNavigator session themselves under the guidance of us as researchers. As stressed by Mor and Abdu (2018, p. 1163) for teachers to encourage epistemic fluency it is important that they undergo the epistemic practice themselves to increase their awareness of the process. It would be interesting to look into the relation between epistemic practice of supervisors and their role in facilitating epistemic fluency in student teams.

5. Conclusion

Our research shows that in their conversations students use different knowledge modes, which are elicited by the moderated sessions through questions of the moderator as well as questions that students ask each other. We have found that by explicitly mapping the disciplinary insights and then zooming in on specific concepts, the team's conversation about different ways of knowledge is encouraged. Although students do not always explicitly reflect on disciplinary epistemological differences, their conversations show that they are actively looking to integrate disciplinary insights to further their understanding of the interdisciplinary research question. This is both a result of their interdisciplinary education so far in that they have learned to seek shared horizons from their first year at LAS, and it is encouraged by the structure of the sessions. In this, the tools provide the learning conditions where students can use and develop their epistemic fluency as they are encouraged to work with different levels of knowledge. Enabling students to piggyback on the level of epistemic fluency of their group members, tool use facilitates the circumstances in which the students can potentially develop a shared epistemic fluency that helps the group work towards a shared understanding of their interdisciplinary research question. As such, this research contributes to the understanding of interdisciplinary knowledge sharing and our aim for the future is to look at additional learning conditions that encourage interdisciplinary collaboration, appropriate to the specific context that the student is working in.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Faculty Ethics Assessment Committee Humanities, Utrecht University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

RvL and FdV have contributed equally to this manuscript and the research that contributed to this manuscript. All authors contributed to the article and approved the submitted version.

Funding

Part of this research is funded by a Scholarship of Teaching and Learning grant at Utrecht University. Information on this grant can be found here: https://www.uu.nl/en/education/centre-for-academic-teaching/educational-scholarship/advice-and-support/sotl-grants SoTL Grants - Centre for Academic Teaching and Learning - Utrecht University (uu.nl) and the granted project can be found here: https://www.uu.nl/en/education/centre-for-academic-teaching/educational-scholarship/scholarship-of-teaching-and-learning/granted-sotl-projects Granted SoTL projects - Centre for Academic Teaching and Learning - Utrecht University (uu.nl). With this money we funded a student-assistant and the tool CoNavigator with accompanying support from Katrine Lindvig, Line Hillersdal and David Earle.

Acknowledgments

This research is inspired by, and makes use of the tool CoNavigator, designed by Katrine Lindvig, Line Hillersdal and David Earle (https://www.conavigator.org/ CoNavigator hands-on interdisciplinary collaboration & problem solving tool). We would like to give our dearest thanks to Katrine Lindvig, Line Hillersdal and David Earle for help with setting up CoNavigator and guidance through the process of moderating the CoNavigator sessions.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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