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Interdisciplinary students' reflections on the development of their epistemic fluency

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Introduction: How can higher education institutions foster students' epistemic fluency, that is, their ability to identify, reflect upon, and connect different knowledges and different ways of knowing? As higher education institutions put interdisciplinary research and education prominently on their strategic agendas, there is a call for knowledge on how to teach students to identify and integrate insights from different disciplines. This study approached this topic from the viewpoint of the student: what are the drivers and barriers to the development of epistemic fluency, according to interdisciplinary students?

Methods: Participants were undergraduate students enrolled in a course on the interdisciplinary research process with a specific emphasis on integration. In the first and last lectures of the course, students were asked to reflect on their openness to alternative perspectives and their connective thinking. They also reflected on their development in general and specifically in this interdisciplinary course.

Results: Students were able to meaningfully reflect on their development and the results showed a varied picture of students' epistemic fluency.

KEYWORDS

connective thinking, multiple perspectives, epistemic fluency, integrative competences, interdisciplinarity, higher education, reflection, modes of knowledge

1. Introduction

As higher education institutions put interdisciplinary research and education prominently on their strategic agendas, there is a call for knowledge on how to *teach* students to identify and integrate insights from different disciplines. How can higher education institutions foster students' epistemic fluency, that is, their ability to identify, reflect upon, and connect different knowledges and different ways of knowing? *Can* these integrative competences be taught – and if so, how? The current study approaches this topic from the viewpoint of the student: what are – according to interdisciplinary students – drivers and barriers to developing epistemic fluency?

In theory, epistemic fluency develops as students move toward the higher modes of knowing as defined by Savin-Baden (2014). Epistemic fluency – the ability 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) – is closely related to what Savin-Baden (2014) calls the upper three modes of knowing (see Table 1, reprinted from Savin-Baden, 2014).

Students in interdisciplinary education encounter these different modes of knowledge as this type of education aims to teach students to integrate insights from different perspectives to ultimately compile a more comprehensive understanding that is more than the sum of its parts (Spelt et al., 2009; Frodeman et al., 2017; Bammer et al., 2020; Repko and Szostak, 2021).

TABLE 1 Modes of knowledge as defined by Savin-Baden (2014).

Mode 1	Propositional knowledge that is produced within academe separate from its use and the academy is considered the traditional environment for the generation of this form of knowledge.
Mode 2	Knowledge that transcends disciplines and is produced in, and validated through, the world of work.
Mode 3	Knowing in and with uncertainty, a sense of recognizing epistemological gaps that increase uncertainty.
Mode 4	Disregarded knowledge, spaces in which uncertainty and gaps are recognized along with the realization of the relative importance of gaps between different knowledges and different knowledge hierarchies.
Mode 5	Holding diverse knowledges with uncertainties.

Reprinted from Savin-Baden (2014).

Integration is "a process of combining a wide range of perspectives from different disciplines (i.e., interdisciplinary integration), as well as from research, policy, and practice (i.e., transdisciplinary integration)" (Hoffmann et al., 2022).

Integrative competences – knowledges, skills, and attitudes that aid integration – are thus at the heart of interdisciplinary education. Two of such competences, and the focus of this study, are *openness to alternative perspectives*, and *connective thinking*. Other relevant competences include curiosity, creativity, sociability, persistence, patience, reflexivity, modesty, humility, vulnerability, tolerating ambiguity and instability, optimism, trust, self-confidence, communication skills, seeing the big picture, "having a thick but not impermeable skin, finding humor in one's own mistakes, being flexible in one's ideas, and being perseverant and unflappable in the face of numerous hurdles on the way towards integration" (Hoffmann et al., 2022).

Epistemic fluency is operationalized as openness to alternative perspectives and connective thinking in this study, since these integrative competences are necessary to move from the lower to the higher modes of knowledge (Sill, 1996). Hoffmann et al. (2022) stress the importance of these two competences:

> Given inevitability of conflicts due to different and sometimes diverging perspectives, especially in heterogeneous ITD teams, integration experts also need the ability to deal with conflicts in a constructive way (Bennett and Gadlin, 2019).

Proponents of integrative interdisciplinarity stress that integrative competences should be taught early on in students' careers instead of only later, because for "people [who] are trained in deeply disciplinary ways, interdisciplinary work becomes an unnatural act (…) and difficult to sustain," (Boix Mansilla et al., 2006, p. 73). This does not only hold for competences such as skills and attitudes, but also knowledge about different disciplines: their boundaries, their differences and similarities, their histories, and their core elements (epistemology, methods, theories, assumptions, phenomena, and concepts; Repko and Szostak, 2021).

As a result of the nature of interdisciplinary education, students in interdisciplinary education can be expected to move through these modes more explicitly or consciously than their disciplinary peers. Or can this be because students who are inclined to do this are exactly the students that enroll in interdisciplinary education? That is, does interdisciplinary education create epistemically fluent students, or are epistemically fluent students attracted to interdisciplinary education? One way to look at this question is by investigating how students believe they develop their epistemic

fluency. By asking them about their development, one can come closer to an answer to the question of whether it is possible to teach these kinds of competences.

The current study explored the research question: how do interdisciplinary students reflect on the development of their epistemic fluency? Participants were undergraduate students enrolled in a course on the interdisciplinary research process with a specific emphasis on integration, using Repko and Szostak's (2021) steps. Data were collected using a survey, in the first and last lectures of the course. Surveys can be used to gather insightful data from a large group of participants at the same time (Braun and Clarke, 2013). Students' development can be studied by asking students the same questions at the beginning and at the end of a course, as well as by asking students about their development explicitly. A descriptive, inductive approach was used for the data analysis.

The context of this study's data collection was an undergraduate program that educates students to become "disciplined interdisciplinarians." It comprises of (1) deep learning through a multi-or monodisciplinary specialization (students choose their specialization from a list of 35 options), (2) broad learning through a general education requirement, (3) integrative learning through a core curriculum, and (4) self-directed learning through reflective portfolios. The unique combination of deep, broad, integrative, and self-directed learning enables these students to gain an understanding of the full breadth of the sciences. Throughout their undergraduate journey, these students encounter all five modes of knowing as described by Savin-Baden (2014). These kinds of curricula are often student-centered and characterized by a community of practice in which students and academic staff work closely together (Dekker, 2020). This study took place in a course in which students are considered to be experts in their specialization and in this role conduct an interdisciplinary research project on a complex problem together with two or three students specializing in different disciplines. This provided a rich context to study students' epistemic fluency development.

2. Materials and methods

2.1. Study participants and procedure

All students who were enrolled in a course on the interdisciplinary research process were invited to participate in the data collection during the first and last lectures of the course. They were all senior students in an interdisciplinary undergraduate program at a European research-intensive university.

Since the study aimed to investigate how students developed in general and in the span of one course, *all* enrolled students – instead of a sub-sample – were invited to participate. In total, 105 students participated in both the first and last lectures, 31 students only participated in the first lecture, and 15 only participated in the last lecture. This made a total of 136 students participating in the first data collection and 120 in the last data collection (some students were not present at the last lecture, or did not want to participate anymore).

Students were informed about what their participation entailed, that it was voluntary, and that their participation was not in any way related to their course results. They were familiarized with the exact aims of the study and gave written consent. Participants did not receive any compensation for their participation.

Data collection took place in the first and last lectures of the course, in six seminar groups. At the beginning of the data collection, the teacher read out instructions to ensure that every group received the same information. Students filled out the questionnaires individually, which took about 20 min in total.

2.2. Researcher integrity

Besides conducting this study, I was also a lecturer in the course. As I taught one of six seminar groups, there was a hierarchical relationship between me and about one-sixth of the participants. I made sure to address this during the study introduction, and data analysis only started after the completion of the course. All data were processed anonymously.

Throughout the research process, I kept a research journal with field notes. For example, I logged how students reacted to the data collection where I was present, and how teachers reported back to me about the data collection in their classes. These notes were not used as data, but were reviewed before and after data analysis to contextualize responses.

2.3. Course context

Data collection took place in the first and last lectures of the course on interdisciplinary research. This was an advanced course, usually taken by students in their second or third year of the three-year bachelor program. The course's intended learning outcomes were: (1) evaluate and compare the methodologies and ways of thinking of students' discipline and other disciplines, (2) design, conduct, and present an interdisciplinarity research project, (3) collaborate in an interdisciplinary team and overcome differences in content and method, (4) reflect on ethical and societal considerations of students' discipline, (5) reflect critically on interdisciplinarity and the interdisciplinary research process.

This course was chosen as the site for data collection because its intended learning outcomes and content provide an opportunity to study development in epistemic fluency, since learning to integrate is an important part of the course. Senior students were also expected to be able to reflect meaningfully on their education and development. The course had two iterations per academic year, and data collection took place in both iterations. The course consisted of several plenary lectures with all enrolled students, and weekly seminars in six groups of maximally 25 students, each taught by one lecturer.

2.4. Material

The data collection procedure entailed a questionnaire with both an online and a paper-and-pencil part. The questionnaire was longer than what is reported here; this article presents a sub-part of the full data collection because of the focus on epistemic fluency, operationalized here as openness to alternative perspectives and connective thinking. Other topics included in the questionnaire were: taking initiative, taking risks, innovative thinking, and curiosity.

Students were first asked to reflect on *openness to alternative perspectives*, and then on *connective thinking*. First, students saw four statements and were asked which statement resonated best with them at this moment. The statements were loosely based on items of the AAC&U VALUE rubrics (Association of American Colleges & Universities, 2017). They were designed to prompt the students to reflect on their epistemic fluency, and hence were not designed to be – nor analyzed as – quantitative self-assessment measures of students' epistemic fluency.

For openness to alternative perspectives, the statements were:

- "I do not usually think about alternative perspectives or ideas."
- "Often I am aware of alternative perspectives or ideas, but do nothing with them."
- "I see the value of alternative perspectives or ideas, but do not always act on them."
- "I see the value of alternative perspectives of ideas and always act on them."

For connective thinking, the statements were:

- "When asked, I can present examples, facts or theories from more than one perspective or discipline."
- "When asked, I can connect examples, facts or theories from more than one perspective or discipline."
- "Of my own accord, I can present examples, facts or theories from more than one perspective or discipline."
- "Of my own accord, I always connect examples, facts or theories from more than one perspective or discipline."

After students indicated which statement fit them best, they were asked to explain why they gave the above answer. To retrieve students' reflections on their development, they were then asked whether they thought they had developed this part of their epistemic fluency, and if so, to elaborate on this. They were asked to name concrete examples of assignments, projects, courses, or other experiences that fostered their development.

The data collection in the last lecture of the course was similar to the first lecture, with the exception that students were now asked to reflect on how they developed *within* the current course.

2.5. Data analysis

The online part of the questionnaire was downloaded and stored. The paper-and-pencil part of the questionnaire was transcribed into digital format for analysis.

The students' answers to the questionnaire were analyzed using a reflexive thematic analysis approach. The thematic

analysis phases of Braun and Clarke (2006, 2013, 2022) guided the analysis process. First, I critically engaged with the data by reading and re-reading, to immerse myself in the data. I grouped the data based on the answers to the self-assessment, first analyzing the answers of students who identified as belonging to the lowest categories, and then moving upwards. Then, I coded the data inductively. Coding categories were based on the data and not developed *a priori*; no analytic scheme was used. Most of my codes were semantic, but I also used some latent codes. Units of analyses varied from individual words to multiple sentences, depending on the content, succinctness, and length of students' answers. I then identified and developed candidate and final themes, staying close to the data. When I felt satisfied with the final themes, the writing stage began.

3. Results

3.1. Openness to alternative perspectives

3.1.1. Openness to alternative perspectives self-assessment

Table 2 shows how students responded to the question: *Which statement on the theme of alternative perspectives resonates best with you right now?* The middle column shows percentages for students' self-assessment at the beginning of the course, and the right column at the end of the course. Between the first and the second measurement, five students moved from 2 to 3, and ten moved from 3 to 4. Ten students moved from 4 to 3, four from 3 to 2, and one from 3 to 1.

Students were asked to explain why they gave the above answer. The section below presents insights from those reflections for the data collection at the beginning of the interdisciplinary course, divided into barriers and drivers. The answers at the end of the interdisciplinary course showed a similar picture and did not lead to additional insights, so they are not presented here. Student quotes are presented with indentations in smaller font size (translated, as the study was conducted in Dutch).

3.1.1.1. Barriers

The most important barrier was the *influence of constraints in assignments.* Students explained that – although they are aware of alternative perspectives – they often do not integrate them due to constraints in the assignments. For some, this is a conscious effort:

> I notice very much that there are different perspectives in different disciplines. So I make sure I'm aware of the relevant perspective first and adapt to it.

This indicates that students consider the constraints in assignments as more important or pressing than the possibility to explore alternative perspectives or ideas, i.e., developing their epistemic fluency. Students consciously deliberated the implementation of alternative perspectives:

> I increasingly see alternative perspectives or ideas because I have developed a broader knowledge. I just don't always do something with it because on the one hand, I weigh up whether it adds something and on the other hand, it is sometimes too much effort for an assignment.

This sometimes led to a certain fear. Students considered whether their success rate would be high enough to risk the implementation of alternative perspectives and the effort it will take to implement them. Time, difficulty, and effort were the most important reasons students gave for not implementing alternative perspectives. They said that it costs more time and effort to implement alternative perspectives because it is more difficult, and that this could mean they would not be able to finish an assignment on time if they were to implement those other perspectives.

Word limits were also mentioned as reasons not to implement alternative perspectives.

> It is always important to question your own perspective and see if there are any other possibilities. But at university, it is often the case that it is better to limit it and not to go into too many perspectives because of time or word limits, in almost every essay.

This student explicitly made a distinction between their epistemic fluency in general and how they can put it into practice in their education. Indeed, some students said that using alternative perspectives is often not allowed in courses, because they are supposed to elaborate on one perspective more deeply. Most students then stick to those requirements, but others try to implement them nonetheless:

> Sometimes I have a problem with the fact that a course only considers one perspective, and I want to oppose this a bit, even though there may be strong evidence for this perspective.

Some students said that sometimes one perspective is enough, especially when you are doing disciplinary work. Some students said they do look into alternative perspectives, but that they often do not implement them because they fear they do not have enough knowledge to implement the alternative perspectives, and then it is safer to stay within their specialisation. Indeed, one student said that sometimes they find it valuable to have one vision and defend that. Some students said they look at other perspectives to try to understand

TABLE 2 Students' self-assessment for *openness to alternative perspectives*, in percentages.

Statement	At the beginning of the course (*n* = 136)	At the end of the course (*n* = 120)
1. I do not usually think about alternative perspectives or ideas.	0	0.8%
2. Often I am aware of alternative perspectives or ideas, but do nothing with them.	4.4%	4.2%
3. I see the value of alternative perspectives or ideas, but do not always act on them.	75.7%	77.5%
4. I see the value of alternative perspectives of ideas and always act on them.	19.1%	17.5%

them, but then they do stick to their own vision. Others indicated that they would like to implement alternative ideas, but do not know how.

3.1.1.2. Drivers

A recurring theme that can be considered a driver was *science and truth.* Many students said that considering alternative perspectives lets them grasp a concept better, or lets them come closer to "the truth", because one perspective cannot be enough.

Others said that considering alternative perspectives makes you more objective because you gain a more holistic overview of the topic.

Students also reflected on science and academia, and the value of alternative perspectives for science:

> Science is ultimately a collection of all kinds of different perspectives and methods. One perspective is therefore no better or worse than the other, as long as you describe why the differences exist.

Another important theme in students' reflections was *joy and interest.* Many students reflected that they enjoy implementing multiple perspectives into their work. They said it piqued their interest, broadens their knowledge, opens their mind, and fed their curiosity and hunger for knowledge. They liked being inspired by others.

> I like to apply elements or topics from courses that I have followed to other courses. I also do this to learn more about topics that interest me.

Practical constraints in assignments, however, negatively influence students' perceived "fun" in making assignments, as mentioned under "barriers":

> I always enjoy making papers and doing research because you immerse yourself in one thing. Quite recently, one of my papers for a course on genocides received feedback that I should focus more on the opinions of other authors instead of my own view. This makes making the assignment less fun, because I hope to contribute something (to a very limited extent, of course) to the field.

Students also valued considering multiple perspectives – even though they may not believe in those perspectives themselves – to broaden their own world view, or to make perspectives clear to – an imagined – audience. For example, a student remembered an assignment in which they had to give the pros and cons of pseudo-science:

> Although I do not believe in it, I think it is important that a different point of view is also heard.

Some students expressed strong feelings about the importance of considering alternative perspectives:

> If you don't respect other perspectives or truths you assume the world is much simpler and easier to read than it is and that's the dumbest thing you can ever do.

For example, some students showed frustration about disciplines, courses, or teachers not accepting alternative ideas.

> I always think critically about myself and the courses I follow and often discuss this in lectures, for example, if a lecturer only provides Western sources, I often look for non-Western knowledge for papers myself, because I despise Eurocentrism. I also sometimes ask the teacher for the justification for this.

The students were also very clear that alternative perspectives are learning opportunities, beneficial for their development.

> I find this super useful, especially when looking at one problem from different angles! Different perspectives will make you see both the problem and your perspective differently.

Further, these students explicitly mentioned seeking new, alternative perspectives to broaden their horizons.

> I always try to be as critical as possible of everything I think and every opinion I have, so as not to get stuck in my thinking. I used to think much less about this, but now it is very important to me.

One person considered this to be a bit of a negative trait:

> I often have trouble forming a clear opinion, because I always understand the other points of view somewhere.

In general, the students found implementing new perspectives fun, valuable, and opportunities for learning, and they also found it necessary for themselves and the world.

3.1.2. Development of students' openness to alternative perspectives in their undergraduate journey

Students were asked to reflect on their development concerning openness to alternative perspectives from the start of their undergraduate journey until now, by the prompt: "If you feel you have developed in this area, please explain that development." The answers were again analyzed per self-assessment category, but are presented here altogether, because there were no significant differences in responses in the categories.

The students' answers were varied, with some students saying have always been open to alternative perspectives, and others said they have learned this since they are in university.

With respect to *how* students said they developed openness to alternative perspectives, some students said they developed it by following many different courses all over the university, others explicitly mentioned their interdisciplinary study path, or the core courses on interdisciplinarity. Others mentioned honours education. One student said this openness comes with age.

Some students said that collaborative projects help them develop this competency, or merely meeting many new people who have different ideas and specializations.

There was also room for development. Some students explicitly said that they found implementing alternative perspective challenging, and others said said they were still trying to develop this competency.

3.1.3. Development of students' openness to alternative perspectives in an interdisciplinary course

At the end of the interdisciplinary course in which this study took place, students were explicitly asked to reflect on whether – and if so, how – they developed their openness to alternative perspectives in the current course in which they were taught the interdisciplinary research process. Students were encouraged to name specific parts of the course that fostered their development.

A couple of students explicitly said they did not develop their openness to alternative perspectives in the course. For some this was because they feel like they cannot develop more in this respect:

> The importance of openness to alternative perspectives becomes very clear in this course, because you collaborate with different disciplines. I haven't necessarily developed this here, because I almost always take it into account anyway.

Others said they did not encounter any new perspectives in the course:

> Presenting alternative perspectives provides a more complete picture of the research topic. But in my opinion, I have not yet discovered an alternative or completely different perspective in my research team in this course.

One student mentioned practical constraints of the assignment:

> I often see too many alternatives and find it difficult to make a choice. The fact that I don't always do something with it is more because of a lack of time or words than because I wouldn't want to include these alternatives. This also holds for this course; the word limit was too restrictive for me, so I didn't develop myself in this respect.

One student reflected on their own perspective versus that of others:

> It's good to listen to others because it can give new ideas, but in this course I didn't adopt the other ideas, because others often give advice from the perspective of their own discipline, which is not always useful in my discipline.

Most students, however, said they *did* develop openness to alternative perspectives during the course.

For some, the course (or this questionnaire) provided room for self-reflection.

Many students said this course raised their awareness of "possible existing biases" in their thinking.

Some learned that there is value in alternative perspectives:

> It is not always practical to include more aspects in an answer, as this could often make it more complex. In this course I did learn to appreciate alternative perspectives and it was emphasized even more that not everyone thinks the same way.

Again, several students mentioned using alternative perspectives to come closer to *the truth*:

> I really enjoy talking to people with other perspectives in order to arrive at the truth. This course puts a lot of emphasis on that, very good!

Others talked about different ways of thinking in different fields of science:

> Because my specialization is very interdisciplinary and is pretty much built on alternative or conflicting perspectives, I can't even separate myself from different perspectives. In this course, I mostly discovered how limiting other disciplines are in their thinking (which doesn't make them superfluous, but I'm glad I have my own specialization).

Specific parts of the course that fostered their developed were: the research project, learning to integrate, being forced to consider other perspectives, being exposed to philosophy of science, merely encountering other disciplines, group discussions, and being stimulated to be creative.

These answers show a heterogenous image of students' development of openness in alternative perspectives in a course in integration and interdisciplinarity.

3.2. Connective thinking

3.2.1. Connective thinking self-assessment

Table 3 shows percentages of students' responses to the question: "Which statement on the theme of connective thinking resonates best with you at this moment?" Again, students' self-assessment at the beginning of the course are presented in the middle, and those at the end of the course in the right column. Between the first and the second measurement, twelve students moved from 2 to 3, nine from 3 to 4, one from 2 to 2.5 and two from 2 to 4. Ten students moved from 4 to 3, one from 4 to 3.5, two from 4 to 2, twelve from 3 to 2, one from 3 to 1, and three from 2 to 1.

Students were again asked to explain why they gave the above answer. Below, insights from those reflections for the data collection at the start of the interdisciplinary course is presented, divided into barriers and drivers. The answers at the end of the interdisciplinary course painted the same picture and did not lead to additional insights, so for brevity they are not presented here.

3.2.1.1. Barriers

Most students said they felt like they need to have enough knowledge to make connections:

> I sometimes still find it difficult to connect examples and such from multiple disciplines, because I do not have sufficient knowledge of all disciplines.

They said that without enough knowledge, they do not think they can make meaningful connections. Some students indicated that they need to be prompted to do it, for example by an assignment. Another student said they need explicit feedback from teachers or peers on their work. Some students reflected on what they found difficult to connect:

TABLE 3 Students' self-assessment for *connective thinking*, in percentages.

Statement	At the beginning of the course (*n* = 136)	At the end of the course (*n* = 120)
1. When asked, I can present examples, facts or theories from more than one perspective or discipline.	0	4.2%
2. When asked, I can connect examples, facts or theories from more than one perspective or discipline.	22.1%	19.2%[a]
3. Of my own accord, I can present examples, facts or theories from more than one perspective or discipline.	49.3%	47.5%[a]
4. Of my own accord, I always connect examples, facts or theories from more than one perspective or discipline.	28.7%	26.7%

[a]At the end of the course, one student (0.8%) circled both statements 2 and 3, and two students (1.7%) circled both statements 3 and 4.

> Although I manage to connect humanities and societal themes (or just different social disciplines) reasonably naturally, I find it difficult to make connections with the natural sciences.

Again, time constraints and other priorities were mentioned as reasons not to connect.

3.2.1.2. Drivers

A common answer was that connective thinking has to do with having a *broad interest*. Students stressed that connective thinking leads to new insights, that it is necessary for innovation, and that they do it to improve society. They also said it is fun and interesting to do, and that they enjoy it:

> It's beautiful when the world "fits".

Some students said it is what *should* be done, and some, again, mentioned "the truth." Many students said this is something that happens automatically, and that it is not limited to their studies:

> I always connect knowledge from courses, conversations, the newspaper, observations and previously acquired knowledge with each other, regardless of disciplines.

Some students said their specific undergraduate program forces them to do this. Some students said this is why they chose this study programme: because it teaches them how to do it and because it gives the students ample room to follow many different courses. Many students said they connect ideas automatically and that it is impossible for them not to do. They said it is how their mind works.

> I often see connections between different topics. This happens on my own. I quickly recognize the different perspectives to one problem.

Some students were contradictory in their reflections, saying it was both automatic and stimulated, and improved by practice:

> Personally, I often connect different concepts from all kinds of courses, but this is also stimulated, so I think it comes naturally because I do it often.

One person said it can also be a negative characteristic:

> I did this as a child and still do. Because of this I can sometimes come across as confused and unclear. There is no limitation in my head, and therefore not on paper. This has caused a lot of conflict in high school.

The reflections showed that this is a complex topic and that students need self-awareness to reflect on this matter.

3.2.2. Development of students' connective thinking in their undergraduate journey

Many students indicated that they consciously developed connective thinking. Others said "there was no development", because "it's how their mind works." But even these latter students acknowledged that their undergraduate education contributed to some development, or that the knowledge they have gained by following different courses has helped.

> I am always looking at things from different perspectives. I haven't changed much in this, but I do know more about different things.

Some said they would like to learn more or develop this more. Some tried to develop this competency explicitly by choosing specific courses:

> It is a work in progress, but I try to choose as many interdisciplinary course as possible. Because of this I notice that my connective thinking improves.

Some specifically mentioned the undergraduate programme's core courses in interdisciplinarity. They said these courses made them aware of connections, and gave them the necessary skills, which gained momentum for this development and use of this competency in other courses or contexts.

> The first core course made me aware of the possibility of simply connecting everything. I think I started doing it more after that.

Some students reflected on other education they have been enrolled in, before they started their current undergraduate programme:

> I like doing it. Sometimes I do it on my own and sometimes when I am asked. I only started doing it when I started studying here. Before this I was always trained to work within one discipline.

3.2.3. Development of students' connective thinking in an interdisciplinary course

At the end of the interdisciplinary course, 45 students explicitly said they developed their connective thinking in the course. One student in particular was very positive about the course:

> To me, problems are never disciplinary and I have always thought it is weird that the world treats them that way. This course is the first time I feel like I can do exactly how it should be done.

Many students made the observation that this course built on the competencies that they developed in previous core courses. According to the students, the current course fostered their connective thinking by: being forced to make connections, presenting, collaborating in multidisciplinary teams, learning to integrate, encountering different disciplines, learning the interdisciplinary research process, the interdisciplinary project, and the disciplinary part of the research project.

The course, or being prompted to reflect on it in the questionnaire, also gave room for self-reflection:

> I am a very open thinker, but in this course I realized that I sometimes fall into the trap of tunnel vision and staying "inside the box". This course has opened my eyes.

Again, the diversity in students' reflections on their development of connective thinking became clear.

4. Discussion

This study asked how students reflect on the development of their epistemic fluency, as operationalized by *openness to alternative perspectives* and *connective thinking*. Students in a self-directed interdisciplinary undergraduate programme, enrolled in a course in which they were taught the interdisciplinary research process, were asked to self-assess and describe their development in their undergraduate education and in this specific course. Specific barriers and drivers for the development of epistemic fluency were identified.

In general, students indicated that they are open to alternative perspectives and that they can connect knowledges and ideas. They reflected meaningfully on their development in these competences and in their journey from the lower modes of knowledge to the higher modes of knowledge (Savin-Baden, 2014). In their answers, students showed epistemic fluency (Markauskaite and Goodyear, 2017). These results and this development are in line with earlier research (Haynes and Leonard, 2010; van der Lecq, 2016).

For both measures of epistemic fluency, almost none of the student self-assessed in the lowest category, meaning that almost all students indicated they at least show some competency in these areas. This could be the case because these students were enrolled in an undergraduate programme where these competencies are important.

Three barriers stood out: practical constraints in assignments, epistemological constraints (i.e., the need for more knowledge), and the need for other people. Practical constraints in assignments were by far the most frequent answers. For example, time, word limits, and specific guidelines could limit students' perceived or realistic options to make connections or implement multiple perspectives. Some students identified particular disciplines that have more constraints than others. Besides for the nature of disciplines, there can also be pedagogical or didactical reasons for such constraints in assignments. For example, even in the core courses of the interdisciplinary undergraduate programme that these students follow, there are assignments in which students are only allowed to use insights from one discipline, precisely because the goal of those assignments is to delve deeper into one discipline, often with subsequent comparison to other disciplines. Thus, constraints in assignments can sometimes have an underlying didactical purpose. It would therefore be interesting to further delve into this tension: what kind of educational or didactical material allows students to develop their epistemic fluency while at the same time fit into constructively aligned undergraduate programmes and courses?

The need for more knowledge was also named as a reason for not implementing multiple perspectives or making connections, as well as – relatedly – need for other people. The benefits of collaboration are well-known. Even in individual assignments, help or feedback from others is welcome. Peer feedback and teacher feedback was regarded as both being beneficial to the development of epistemic fluency. This demonstrates the social side of education, interdisciplinarity and integration (Boix Mansilla et al., 2015; Pohl et al., 2021; Hoffmann et al., 2022).

Drivers for the development of epistemic fluency were also identified. Students emphasized that being open to alternative perspectives and connected thinking leads to getting closer to "the truth." They said this is essential and indispensable for science, and for addressing societal issues. Students sometimes expressed emotion and affect in their reflections. They wrote about joy and pleasure, but also about fear and taking risks. Indeed, interdisciplinarity and integration in particular has been shown to be emotional processes (Boix Mansilla et al., 2015; Pohl et al., 2021; Hoffmann et al., 2022; van Goch and Lutz, 2023). In reflecting on openness to alternative perspectives and connective thinking, students also mention other competences, for example, creativity, curiosity, and risk-taking. These have indeed been shown to be beneficial to integration and interdisciplinarity (van Goch, 2018; Darbellay, 2022; Hoffmann et al., 2022).

In terms of the conscious development of these epistemic fluency measures, a diverse image emerged. Some students said they have always "done this" and thus did not develop these competences, others said they have indeed learned and developed these competences. Some students indicated that they purposefully chose the specific undergraduate programme they were in because they knew these competences are explicitly taught in the core courses. Others said they chose this specific programme because they already knew how to do it and therefore thought the programme fit them well.

The results of the questions on development in general and in the course under investigation, showed that interdisciplinarity and integration do not happen by itself. Although students said they learned a lot from following many different courses and encountering various disciplines, explicitly being taught the interdisciplinary research process step by step was most beneficial. Students call this "being forced" to do it this way; teachers have also indicated this aids learning processes (van Goch and Lutz, 2023). Indeed, integration is considered difficult (Hoffmann et al., 2022) by both students and teachers (van Goch and Lutz, 2023). This also relates to the emotion and affect evident in students' reflections.

Some of the insights that students said they had learned in the current course, have also been taught to them in previous core courses on interdisciplinarity. This indicates that doing the work instead of merely learning about it has better learning potential. For example, collaborating with students who specialize in a different discipline, working together on an interdisciplinary complex issue, seems to be more instructive than learning about those disciplines. Students' grounding in their specialization probably also plays a role here: during the previous core courses, they had not chosen a specialization yet. As Hoffmann et al. (2022) illustrate:

> training in [inter- and transdisciplinarity] early on is particularly useful in building ability to understand the socially constructed nature of disciplines, to appreciate different disciplines and perspectives, to identify their strengths and weaknesses, and to recognize limitations of one's own field of study (Lattuca et al., 2012). This multi-layered ability is crucial for thinking (and acting) in an integrative manner.

Most of the students in this study were indeed capable of reflecting meaningfully on their epistemic fluency and development thereof, both in the longer period of their undergraduate education, as well as the shorter period of the course this study focused on. Savin-Baden's (2014) modes of knowing are evident in students' reflections, as well as specific contexts that led them to move to higher modes of knowledge. Students showed metacognitive awareness (Flavell, 1976; Weinert, 1987; Hartman, 1998), for example when they reflected on consciously choosing if, when, and how to integrative alternative perspectives, or think connectively. In describing their experiences, students exhibited declarative, procedural, and conditional knowledge. They showed metacognitive regulation by planning, monitoring, and evaluating. This clearly shows students' epistemic fluency: they can identify, reflect upon, and connect different knowledges and ways of knowing (Trede et al., 2019).

The results of this study lead to several suggestions for future research. First, since this study was exploratory, surveys were adequate for the study's aims. Although surveys are a useful way to collect information from a large number of participants (Braun and Clarke, 2013), to delve deeper into these topics, focus groups or interviews could be held. Second, this study used students' reflections to investigate the development of their epistemic fluency. Self-assessments are useful for answering research questions as the current one, but could be less ideal to pick up small developmental changes as in this study. Third, the participants of this study were already involved in interdisciplinary education. In order to formulate suggestions for a broader student body, it is important to also gather reflections of other types of students. The current results could be compared to reflections of students who are not following a self-directed interdisciplinary undergraduate program, and who for example are taking an interdisciplinary course for the first time. Fourth, this study used prompts to elicit students' reflections. These prompts may have influenced students' answers. Future research could use more general prompts, or find other innovative ways to stimulate students' reflections. Fifth, this study was conducted by a single researcher. Although this is not exceptional in qualitative research, it would be interesting to see if other researchers or teachers, or even students, would arrive at similar conclusions. Future research could even incorporate group reflection into the research design.

This study gave insight into how students reflect on the development of their epistemic fluency. Besides the implications for theory, the insights were useful for practice. The tension between the development of epistemic fluency and the barriers against such development should gain more attention. Practical constraints such as time and word limits seem to be detrimental to students' development. Of course, such constraints are not in place to hamper the students at all, and as such teachers and students could work on finding ways to develop epistemic fluency within the boundaries of an assignment or course. Teachers could show students how they can implement alternative perspectives within a certain word limit, or groups of students could brainstorm innovative ways to connect ideas.

Ideally, in higher education, research informs education, and education informs research. These kinds of projects are therefore essential when trying to answer questions of how higher education institutions can foster epistemic fluency and integrative competences. Thorough research into these and related concepts, their interrelations, and their development, is essential to develop effective education strategy and practice.

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 study was conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MG designed, conducted, analyzed, and wrote the research reported in this article.

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Conflict of interest

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

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