The implementation of interdisciplinary employability skills in a futureproof materials science curriculum: a case study

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Abstract

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The interdisciplinary Master of Materiomics aims at educating students to tackle societal challenges such as climate change, energy transition, pandemics, etc. by developing innovative and sustainable materials at the interface of physics and chemistry and employing both experimental and theoretical/computational approaches. Interdisciplinarity forms the backbone of the master and is gradually introduced through the curriculum by means of an interdisciplinary learning line, building on the four learning mechanisms from boundary crossing theory. The aim of this research is to investigate how the interdisciplinary learning line is implemented in the master and which factors promoting or hindering this implementation were experienced during teaching. This is investigated by means of focus groups with the lecturers of the master. The outcome of these interviews form the foundation for ongoing design-based research which aims to optimise the curriculum and interdisciplinary learning line on a yearly basis.

Paper/Presentation

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Global context

Society is currently confronting a series of intricate and inherently interdisciplinary grand challenges, including climate change, the energy transition, pandemics, secure communication technologies, evolving industrial processes, innovative space technologies, and decreasing finite resources. The development of breakthrough materials is a critical component in the search for solutions to the aforementioned societal issues. Hence, addressing these challenges necessitates a strong need for scientists in the field of materials development and researchers who are ready for an internationally-oriented and interdisciplinary research environment and labour market. Employers need more and more scientists who can work in interdisciplinary teams, who have a general overview, and speak each other's language.

Futureproof curriculum design

Developing interdisciplinary competences in students is necessary in light of the complex societal (interdisciplinary) grand challenges and responds to the needs of both regional and international employers in this regard. Hence, from the first design of the new master of materials science at our university (Master of Materiomics), an interdisciplinary approach was taken as the backbone of curriculum development. The curriculum was developed by subject-specific experts with interdisciplinary research expertise in materials science, educational experts in curriculum design, and in consultation with stakeholders (interviews with CEOs and directors of materials-related companies).

As materials design is an interdisciplinary field, the newly developed study program is aimed at students who want to develop innovative and sustainable materials at the interface of physics and chemistry and on the basis of both experimental and theoretical/computational approaches. The student can choose between 4 possible areas of specialisation: energy generation, storage and efficiency; circular processes; materials for quantum technologies; or materials for innovative healthcare. Since students entering the master mainly come from (monodisciplinary) academic bachelors in chemistry or physics, interdisciplinarity is introduced gradually throughout the curriculum, building on the four learning mechanisms from boundary crossing theory (Kluijtmans, 2019, based on Akkerman & Bakker, 2011): identification, coordination, reflection and transformation (Figure 1). These form the core of the interdisciplinarity learning line at the Master of Materiomics where students cross the boundaries between physics and chemistry and an experimental and theoretical/computational approach:

- Identification: students are introduced to the different perspectives and approaches;
- Coordination: here the focus is on making connections between the different perspectives;
- Reflection: considering different perspectives and learning from them;
- Transformation: developing new (material) solutions by integrating different perspectives.

Figure 1. The four learning mechanisms of boundary crossing theory (Akkerman & Bakker, 2011; based on Kluijtmans, 2019, p. 8)

Based on each of these mechanisms, interdisciplinary learning outcomes are formulated which can be incorporated into the different courses of the master. More specifically, before the beginning of the academic year, each coordinator of a course indicates which interdisciplinary learning outcomes apply to his/her course. The educational management team reviews whether all learning objectives are adequately addressed throughout the curriculum and whether they are in line with the proposed interdisciplinary learning line. In this way, throughout the curriculum, students are gradually introduced to different perspectives and approaches, starting by making connections between different perspectives, then synthesising them (e.g. through assignments, group work...), and finally applying all this to new, complex material problems (e.g. through a hands-on project, internship and the master's thesis). In order to maximise the development of interdisciplinary competences among students, a learning portfolio is used which is discussed three times a year with a mentor (professor of the master). Core topics of this mentor program/learning portfolio are the interdisciplinary skills, along with academic skills and the other employability skills the students train during the master (i.e. communicating and presenting, multi(/inter)disciplinary collaboration, thinking and acting ethically, stakeholder awareness, self-management). Students track their development regarding these competences by means of the portfolio, receive feedback from their mentor, and formulate action points to further improve them during the master.

Facilitating and impeding factors

Our aim is to expressly embrace evidence-based practices to provide faculty and students with comprehensive support for interdisciplinarity and the corresponding development of competencies. During the curriculum's developmental phase, we prioritised the establishment of a clear vision on interdisciplinarity, as well as the delineation of the interdisciplinary learning line throughout the curriculum. Moreover, numerous professional development sessions focused on interdisciplinary instruction and evaluation have already been held for the participating lecturers, as well as yearly education days for the educational team.

The study program started this academic year (2022-2023). Also, in this implementation phase, we aim to support the roll-out of the interdisciplinary competence development by design-based research (Anderson & Shattuck, 2012; Dissanayeke et al., 2016) including feedback from students and lecturers. Students and mentors were invited to provide a mid-term evaluation of the mentoring program. Moreover, every semester, we organised focus groups with the educational team of the Master of Materiomics to closely monitor the practical implementation of the interdisciplinary learning line. The feedback generated from these focus groups serves as the foundation for a design-based research (Figure 2) that aims to optimise the curriculum and interdisciplinary learning line on a yearly basis. Currently, we are in the phase of 'iteration 1', whereby our paper reports on the implementation and analysis phase of our design-based research process. More specifically, in this paper, we report on the experiences of lecturers regarding factors that promote or hinder the

implementation of the interdisciplinary learning line. We highlight the primary benefits and challenges encountered with regards to interdisciplinarity, and discuss possible improvement for the future (refinement).

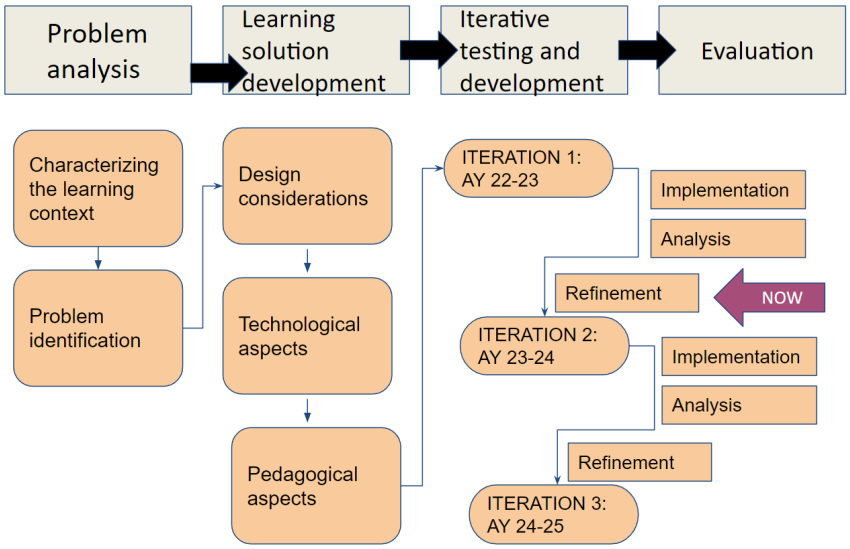

Figure 2. Design-based research process of the master (based on Dissanayeke et al., 2014, p. 14)

Methodology

For each course of the first semester of the first master in Materiomics a focus group interview was organised bringing together all the lecturers contributing to that specific course. In total 8 focus groups took place in which the participants (min. 2, max. 6, median 4) reflected on a standardised set of questions about interdisciplinarity and how it is implemented in that course (see appendix for the questions). The interviews were held in English or Dutch, therefore the quotations reported below are either original responses or translated from Dutch to English. The recorded interviews were transcribed, pseudonymised and subsequently analysed to identify recurring themes or categories of responses by the first author. These form the basis of the results reported below.

Results

Here, the main findings of the focus group meetings are presented. Across the different focus groups, there were diverse responses to the questions. The different themes were identified and categorised under three main categories; (1) definition of interdisciplinary education and the formulation of course specific interdisciplinary learning goals, (2) positioning of the courses on the interdisciplinary learning line and (3) the interdisciplinary conceptualisation with its promoting and hindering factors. Below, these themes are discussed in turn and the cited quotations are written in italic.

1. <u>Definition of interdisciplinary education and the formulation of course specific interdisciplinary learning goals</u>

Although, during the conceptualization of the master's curriculum numerous professional development sessions focusing on interdisciplinarity and its implementation have been held for the educational team, still the participants of the focus group interviews found it rather difficult to formulate their perception of interdisciplinary education.

I think there the big problem lies with the definition of what do you want to call disciplines.

It was also very striking that the teaching team could not easily pinpoint the interdisciplinary learning goals connected to their course.

> *I am sure we had specific goals, but I don't have the study guide in front of me, so I do not recall exactly what, which goals there were.*
>
> *I should refer to the learning objectives and the final competences defined on that. I don't have that at hand right now. [Um] So I would have to call in an emergency line for that.*
>
> *I am currently looking to what we filled in in the matrix of our interdisciplinary learning line.*

This indicates that further investing in professionalisation sessions or education forums on interdisciplinary education might be useful and required. Especially since the lecturers in this master do not consider themselves being interdisciplinary as cited several times.

> *… we do not consider ourselves interdisciplinary …*
>
> *My biggest challenge is that I don't consider myself interdisciplinary …*
>
> *… everyone brought their own expertise …*

Lecturers who attempted to explain interdisciplinary education in their own words mainly looked at interdisciplinarity from a content perspective.

> *Interdisciplinary education in general would mean that you combine aspects of different disciplines within your teaching.*
>
> *Quite simply, that content comes from different disciplines.*
>
> *But in these kinds of courses, afterwards the students know more than us and that's the sum of all the teachers together, I think. There's [um] themselves going to have to make those links and we can't always help with that because we ourselves are not experts in the other part. Maybe that's the difficulty then, or that's interdisciplinary teaching then …*

It can be clearly seen from the answers of the lecturers, that the courses at the first semester of the first master year mainly focus on introducing disciplines and concepts with the goal to combine different contents, rather than integrating or converging as associated with interdisciplinarity. So one could argue whether those courses are really set-up in an interdisciplinary approach. However, one must remark here, that although these courses are merely situated at the beginning of the interdisciplinary learning line (see below) that still some interdisciplinary competences are acquired within the students, see also further. The students first need to master the different disciplines, before they can integrate their knowledge to ultimately reach new insights. This is also reflected in the learning goals which were formulated for each course. Most of these learning goals are interdisciplinary in nature but situated at the beginning of the interdisciplinary learning line as they are focusing on filling knowledge gaps and getting to know the "language" of the other disciplines, both with the aim of building on this in the more interdisciplinary follow-up courses and to be able to communicate and connect with researchers from the other disciplines in the future.

> *… speak the same language in order to be able to connect with colleagues or to co-students to discuss topics from different angles*
>
> *It is mainly the language, to allow them or to make them understand the differences between physics and chemistry. Filling the gaps in the sense that they can follow better an*

interdisciplinarity approach where physics is a part of it. But also formulating, let's say knowledge gaps in the future.

I think the most important thing now for this course was for someone with physics education to get to know the language of chemistry or the basics of the language of chemistry so that from there, and that is how the curriculum was set up, to be able to do the following courses together, to be able to work with the two insights together.

So the interdisciplinarity approach is … that we tried to analyse the knowledge gaps they specifically have and trying to fill them in order to prepare them for later interdisciplinary, more interdisciplinary discussions in the field.

… that they learn the basics about different materials domains which applied to different fields which they further on can build on.

… we should teach them enough basics, so they have antennas and can ask questions.

… to communicate with each other …

2. Position on interdisciplinary learning line

During the focus group interviews, the lecturers were asked to situate their course on the interdisciplinary learning line from identification, coordination, reflection and transformation. This exercise was rather challenging, and usually connected with a long discussion between the participants of the focus groups. Two types of courses can be identified, the ones which are very much focussing on giving the students a decent foundation of one or more disciplines in the field of material science, and others which go already a bit further in linking different disciplines together. The lecturers pinpointed the first type of courses mainly at the beginning of the interdisciplinary learning line (identification and coordination), while for the other type of courses also some aspects further on the learning line (reflection and transformation) were touched upon. In this discussion the lecturers often referred to specific content, learning goals of the course, but also to teaching methods or practical organisation of the course.

Courses at the beginning of the interdisciplinary learning line:

That will definitely be situated at the position of identification. Since that the students have no background whatsoever and we are building that background in this course for a lot of different topics.

The course teaching physics for the chemistry is meant to be a necessity in the beginning of the process, so very much the identification.

…, I mean for coordination it says that the focus is on making the connections, [um] we do this, but I am not sure the focus is on it. For sure identification and then a bit of coordination, …

… but they were collaborating in using each others' pre-existing knowledge. That was I think coordination.

Courses with aspects already touching upon interdisciplinary competences further on the interdisciplinary learning line:

If you look at [content], in the first week you had a physicist and a chemist both giving exactly the same thing. And then in module 2 I am also giving the same thing yet again but then from

the computational point of view. So it is in there, it is the identification but already going into the reflection on how things are being confined and connected to different points of view.

So they certainly did weigh up and learn from the different perspectives, which they actively and effectively had to do, both in preparation for the debate but also reflecting [um] after the outcome of the debate, and that actually got distilled into a mini-essay they then submitted.

Reflection, that considering, is still guided…

…, the seminars were geared more towards the transformation side of it.

When one orders the courses, based on the reflections of the lecturers during the interview, on the interdisciplinary learning line, one can see through the first semester of the first master year already that the students' progress on the interdisciplinary learning line in the direction of transformation (see Figure 3). This was indeed the ambition when creating the Materiomics' curriculum. One lecturer remarked, however, that reaching the transformation phase of the interdisciplinary learning line is very ambitious.

In fact, I think transformation is very ambitious for a master's if they do it after their PhD, I will be satisfied already

Also keep in mind, this last one, transformation. This is very difficult. We ourselves, me myself, are not able to do this like regularly on a daily basis.

If the students reached this phase, whether or not under guidance of a supervisor, should be examined next year after graduation of the first pioneering materiomics' students.

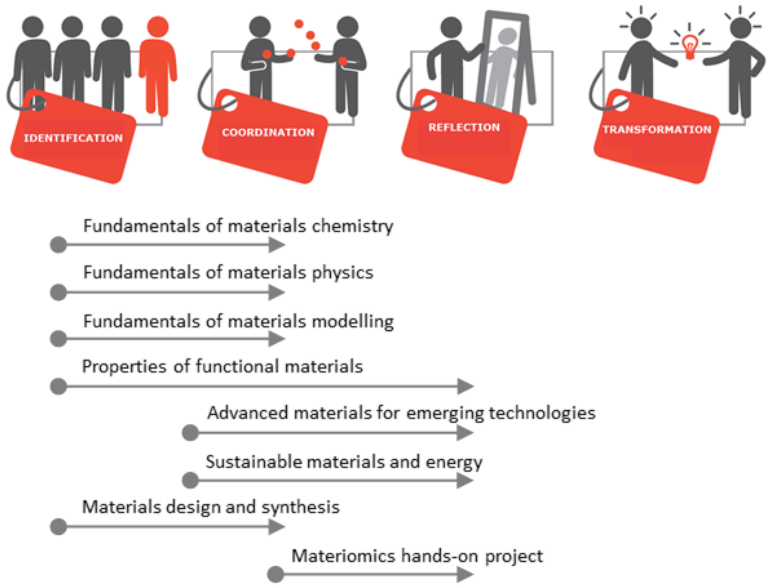

Figure 3. *Positioning of the courses on the interdisciplinary learning line. The dot indicates where the course is mainly situated. The arrow indicates up to which phase activities were organised.*

3. Interdisciplinary conceptualisation and the factors promoting or hindering its implementation

The main goal of these focus groups was to share insights between the lecturers how they implemented interdisciplinary education within their courses. Therefore, during the interviews we dived deeper into the opportunities and challenges related to interdisciplinarity which they

experienced during their teaching assignment. The first recurring aspect is the expertise of the lecturers in connection with each other but also with the students. All the courses were given by a team of lecturers, each coming from a different expertise. This is a real advantage since in this way the interdisciplinarity related to the scientific content can be ensured.

> … *everyone brought their own expertise, so it was really needed that we did this in a team …*

> *…, I think it is because we have a team of three experts. That it is possible to teach these very different content, different modules at a very high-quality level. I think the added value of having a team of professors is, that it allows very high quality every module.*
>
> *It is true that these topics were given by people who are also dealing with certain subjects. So, the reach of these topics is really much higher because we can really inspire them with very state-of-the-art examples that they really can relate to.*
>
> *if one person has to give both views, mine would always be coloured by a more physics equation background.*

But coming from a very specialised, monodisciplinary background also imposed challenges for the lecturers. Having a good course coordinator who keeps the overview and who structures the course is necessary to combine the contributions of the different monodisciplinary experts into one integrated course:

> … *the alignment between the different parts and the different people involved that that went well but that's partly also because the line was made a bit on Blackboard (electronic learning platform). Because there [um] … everyone who was involved had an overview.*

In addition, lecturers are challenged when they are confronted with a group of students having a background opposite from their own expertise.

> *Since I am from physics, so maybe someone from chemistry can join the exercise class that I gave to give some comments on the chemistry side.*

Also, the variety in prior knowledge of the students, due to following different bachelor programs and choosing different elective courses, imposes challenges during teaching. Lecturers really needed to adapt the course content based on the students who are following the courses.

> *So they were probably lacking a few parts with maybe another chemistry student would have had. So that is what I mean that it really depends looking at who is participating.*

> *I saw a big differences in the topic that I presented there between the chemistry and physics students for sure. Several physics students didn't answer my question. So, I also saw that in my lecture as well, there were big differences between just how quickly they picked up the content and how comfortable they were with it.*

> *And it was challenging for my perspective to give a lecture to people from such a very different background. I found it a balance between challenging them and pushing them to far, was difficult to reach. … So, finding that right balance, like bringing everybody along and making sure that everyone learns something, I found it challenging.*

With proper preparation of the lecturer or on the spot acting on differences in the students' prior knowledge, this challenge could be overcome.

I posed the question, I think a 100 times "Is this new for you or not". Depending on the answer I could focus on one thing or the other.

I tried to look into the courses that the students had before. But that was mainly to make references to the courses and also the use the correct jargon or make connections between jargons when there is a difference.

Because, I didn't know what the background is, I talked with [professor name] actually to hear what was given to them in the first semester on physics, where to start.

Related to the selection of content, several lecturers were also struggling with finding the balance between the quantity of topics to present to the students within one course and the depth of those topics. This is a typical phenomenon when creating and bringing content in an interdisciplinary course where also only a limited amount of time is available for delivering the content to the students. Very often the lecturers stated that for the topic they presented, they could easily devote a whole course to it.

The challenge is to have sufficient depth but still that the slide and the courses are still appealing for all students

… biggest challenge is presenting so many concepts on a fundamental level but then having the opportunity to tie them all together

If you get broader than this, then two things can happen. If you combine that with a sensible level of depth then they totally cannot handle it anymore, then it goes too far. And if you make it broader on the cause of depth than depth wise it becomes too trivial.

I would say that from the vast amount of topics together, it is a challenge to pick the ones which are most important and to dig there deeper.

In addition, the lecturers also needed to think how the students would capture the content in an interdisciplinary way and not only look at the content from the perspective of their own background discipline. During the focus groups several teaching formats or learning approaches were suggested which would help students' interdisciplinary learning. Several lecturers either tried by means of inviting experts to give seminars or by constructing the course content in a way that they end with the actual applications which can only be understood by a combination of the fundamentals of different disciplines.

… the other example was actually the expert lecture, …

I think the different modules are linked together quite well with the seminars. We covered a fairly broad number of topics in the seminars. So really applying the fundamental concepts that were taught at the beginning in an interdisciplinary manner. So, all of the topics that were given in the seminars were by nature interdisciplinary.

… it is very interdisciplinary with this split between fundamental concepts and then applications. So the application are really putting all the concepts together, I see that as the interdisciplinary aspect of the course.

Another lecturer also made the remark, that since the interdisciplinary content is presented in one course, the students now know that this content is related or can be connected in the end.

…, just having the topics together in one class, creates in the students their mind the idea that these things can be connected even if we do not explicitly show how they are connected … And

here we just show them a lot of things and it all fits in one course, so it is all connected for them now.

A very interesting approach of teaching to bring interdisciplinary education to a higher level is giving the lecture with two experts simultaneously in the classroom. In this way an entertaining discussion can take place between the two experts where the students can experience the approaches of the two disciplines at the same time. From evaluation meetings with the students, the students also repeatedly said that they really liked this approach, as they could more easily see the interdisciplinary nature of the subject and that they felt that they were really following an interdisciplinary master.

Basically, [professors name] and me were in the same classroom and we talked about [scientific content], first from the physics stand-point, mine, and then [professors name] from chemistry stand-point.

… that you have a supervisor from chemistry and a supervisor from physics, that that actually works very well to let those students see both aspects.

For example, through that joint exercise session between [professors name] and me. Because we had the intention there, yes, to present a problem where they had to bring together both the physics side, or what they had learned with the physics professor, and what they had learned with me (for your information: chemistry side)

… in certain moments or contact moments effectively interaction between different people, between different teachers at that time, at the same time in that work session

Another method to promote interdisciplinary thinking by the students is by means of assignments which run throughout the whole course. This approach was implemented in different courses, and turned out to be working very well, despite the high workload the students might experience if assignments' deadlines coincide.

But there is actually a transition there in the assignment, that debate sheet, is actually an assignment that runs through the modules.

And they had [um] a paper task on [scientific content] so there they could also incorporated the knowledge on the different modules they gathered along the way.

After each module the students had to read the same paper again and again and each time they got questions and these questions came from both physical and chemical backgrounds.

But the most interdisciplinary course in the first semester of the first master year was the Materiomics hands-on project, where the students were confronted with a material design challenge and tried to tackle this challenge in interdisciplinary groups of students supervised by an interdisciplinary team of researchers and by means of hands-on practice in interdisciplinary labs. In addition, the students were evaluated by their group report, group presentation and ability to answer questions coming from both disciplines.

…, this project, this course, I think this is one of the best methods of getting it interdisciplinary, …

… each group contained 1 chemist and 1 physicist …

… how you have organised it now with those two supervisors in the end, that you have a supervisor from chemistry and a supervisor from physics, that that actually works very well anyway to let those students see both aspects.

… and they work in two labs … (for your information: chemistry and physics lab)

… that they have to write a report together, that together they have to arrive at the result they both need, for that they have to communicate with each other, understand each other, and yes, and in the end they both have to understand the report plus they have to present it again to the others who then also ideally have to understand it.

… during the presentation you might be able to assess that they can both answer questions both on the physical and chemical part …

In the end, regardless of the approach chosen by the lecturer to promote interdisciplinary learning, all depends on the student's willingness to submerge themselves in the interdisciplinary way of thinking. Luckily the lecturers experienced very open and interactive attitudes from the students. The students even spontaneously helped each other and very often studied together which supports their development of interdisciplinary competences even further.

What I also noticed, I was really surprised by that, is how open these students were to this other discipline. And probably this has to do with the fact that they consciously chose Materiomics as a study. I think if we had told this story in a traditional physics course, we wouldn't have had quite this much resonance.

…it was definitely not a one-way street.

…at one point the physicist had a little bit more knowledge about the topic than the chemist and vice versa and then it was very nice to see that they were explaining each other in the context

There were some aspects of the [um], some topics are a little bit difficult for the chemists and vice versa for the physicists as well. And they really tried to exchange the knowledge and then that they also tried to help each other.

If they start this course with a certain biased attitude from their own discipline, it cannot work here, it is impossible. Then they won't be motivated to immerse themselves in a certain role, to go looking for things, to actively look for things, to have their own thoughts about it, ... If they don't do that, or start with a certain bias, this ... can fail or be much less qualitative anyway.

Conclusions

Recently a new master in material science started at Hasselt University. In this Master of Materiomics an interdisciplinary learning line is intertwined within the curriculum. To ensure the quality of the master's curriculum and the effective implementation of the interdisciplinary learning line, a design-based research is ongoing. Through iterative cycles of implementation, analysis and refinement, it is the aim to discover what is already going well and to formulate improvement points for the future. Focus groups were organised with the lecturers of the different courses from the first semester of the master, and the results from these focus groups serve as the foundation for the design-based research (analysis) which aims to optimise the curriculum and interdisciplinary learning line on a yearly basis.

From the focus groups it was clear that not every lecturer was able to formulate in their own words what interdisciplinary education should look like. Since monodisciplinary lecturers are teaching the courses, regular professionalisation sessions are needed to get them familiarised with the didactics of interdisciplinary teaching. During educational forums the outcome of the focus groups was shared so the lecturers learn from each other's experiences, especially relating to the challenges that the other

lecturers faced on interdisciplinary teaching and how they try to overcome these challenges. In addition, those professionalisation sessions are the ideal forum to share good practices amongst them.

This research showed that the interdisciplinarity in the master of Materiomics is reflected in the subjects introduced to the students, but also in the way of teaching. The courses in the first semester of the first master year are mainly situated at the beginning of the interdisciplinary learning line and have a focus on providing a decent knowledge foundation for the separate disciplines (chemistry, physics, experimental, computational) and introducing them to the discipline specific jargon, which would facilitate communication in interdisciplinary teams in the further. Some courses have aspects which help the students to grow further on the interdisciplinary learning line. Examples of interdisciplinary approaches are team teaching (preferably also together in one class room about the same content but then from two different perspectives), assignments running throughout the complete course where students need to integrate the new content from the different modules in due course, group projects where students are working in interdisciplinary teams guided by an interdisciplinary expert team and in different contexts (e.g., chemistry and physics labs). However, the success of interdisciplinary learning is highly dependent on the attitude of the students. Since our students made a conscious choice to study this interdisciplinary master, they are highly motivated to transform their initial mindset into the interdisciplinary way of thinking. In the second master year the students are expected to further progress in obtaining interdisciplinary competences and the lecturers need to consider how they can support the students further in this evolution. The success of this interdisciplinary competence development will be a subject for future research.

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Appendix

1. Introduction question:
   Can you please explain which responsibilities you had within the course?
2. Transition question:
   Can you describe your overall experience in teaching in this course?
3. Key questions:
   a. When you think about interdisciplinary education, what does it look like for you?

b. b. Are you aware of the interdisciplinary approach in the curriculum materiomics and can you explain where this course is situated on this learning path? (identification, coordination, reflection, transformation)
c. Which interdisciplinary learning goals or outcomes did you formulate for this course? What do you want to achieve with your students regarding interdisciplinarity/what will students learn in your course regarding interdisciplinarity?
d. How did you incorporate interdisciplinary education in this course, both in teaching and evaluation? Do you have examples?
e. What is your biggest challenge to incorporate interdisciplinary education in this course?
f. If you see it necessary, What can be improved to incorporate (more) interdisciplinary education in this course?
g. If you see it necessary, What kind of support would help you to incorporate (more) interdisciplinary education in this course?
h. Did teaching in a team help/hinder you with implementing interdisciplinary learning goals? (Did you link the different modules together?)

4. End questions:
   a. Is there anything additional you would like to say about your teaching experience or interdisciplinary education in this course?
   b. Of all things discussed today related to interdisciplinary education, what do you think is the most important?