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Educational Reconstruction as a Model for Designing Science Teaching at University

Insights from a Massive Open Online Course for Early Career Science Instructors

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Abstract: Dropout rates for university students in STEM fields are high, and students often cite poor teaching as contributing factor. Improving the teaching skills of university science instructors needs a different approach from school-teacher training, as university instructors often have different career goals and different views of the role of students in learning. In this paper, we present "Teaching Science at University," a professional development course focused on developing pedagogical content knowledge (PCK) and grounded in the Model of Educational Reconstruction (MER) as a framework for the design of teaching interventions. Course participants are early career scientists (PhD researchers to tenure-track professors) with expertise in their scientific field, but little educational training. They start the course with sophisticated content knowledge (CK), and through the course, they gain content- and audience-specific pedagogical techniques (PCK). To assess the effects of the course, we analyzed participants' assignments (n=63) and pre- and post-course surveys (n=100, 54). We found that participants demonstrated increased valuing of student-centered teaching, especially the consideration of students' prior knowledge. We found participants were not only able to build conceptual change interventions specific to their learners' levels of knowledge, but that they also expressed appreciation for the structure that the MER provided to the design of teaching and its role in emphasizing student conceptions. We conclude that PCK-based teaching training should have a role in improving instruction in higher education. We also conclude that the MER provides a useful framework for the design of teaching interventions by science instructors at the university level, and we propose a five-step MER approach for daily teaching practice.

Keywords: Model of Educational Reconstruction, pedagogical content knowledge, graduate teaching assistant, GTA, higher education, professional development, conceptual change

1 Background

A rapidly changing world requires a citizenry well trained in analyzing problems and developing solutions. It is no wonder that there is a high demand for university graduates with degrees in science, technology, engineering, and mathematics (STEM). Simultaneously, however, university dropout rates for students in STEM fields are high, and students cite poor teaching as a key factor in their decision to discontinue their studies (e.g. Seeman & Gausch, 2012; Yorke & Longden, 2008). For those who make it to graduation, they often find it difficult to translate their good factual knowledge about scientific content to the novel tools, techniques, and working demands of the STEM fields (Labster, 2019). When we look inside universities, we see people tasked with significant amounts of teaching to audiences of students too large to interact with on a personal basis. They are usually professional scientists with little formal teaching training. They are often driven by research excellence and working in environments where teaching excellence and personal development in teaching take lower priority. In addition, they have been highly influenced by the lecture-style, information-transmissive teaching they themselves received as university students and still receive at science conferences and research symposia.

Improving the teaching skills of university science instructors is not a straightforward task. Much of what we have learned from the research on school teacher training cannot be directly applied to universities due to the differences between school teachers' and university instructors' professional goals, expectations of students, and institutional cultures (Oolbekkink-Marchand, van Driel & Verloop, 2006). In addition, professional development for schoolteachers often focuses upon content knowledge or a particular curriculum (e.g. Halim & Meerah, 2002; Appleton, 2003), which would be inappropriate for university science instructors who are typically specialists in their fields and have broad autonomy to design their own courses. And while most universities have centers for teaching and learning that have long offered courses in general teaching skills, the dropout rates in STEM remain high. We make the case here that a different training approach is necessary, one, which selects from general pedagogy those aspects, which are most useful for university science teaching and learning, and gives scientists the time and motivation to directly test them out in their teaching.

We take an educational design research approach to the problems discussed so far, which means we aim to develop both practical solutions and knowledge through our research. Our practical aim is to further develop and refine an introductory course on science teaching and learning at the university level, which we have taught in various formats since 2011. The course is called "Teaching Science at University" (TSAU), and its purpose is to introduce early career science instructors to science-specific pedagogical knowledge, which will enable them to teach more effectively. The course is also the core of our research and is our vehicle to assess the relevance and utility of concepts and models from educational research, namely pedagogical content knowledge (PCK) and the Model of Educational Reconstruction (MER). In our study, we make use of the MER differently than it has been used in most previous studies; we do not aim to use it as a research model but rather as a framework to give science instructors a structure for drawing upon their students' everyday conceptions in their design of lectures, lab classes, excursions etc. in higher education.

2 Insights from research

Teachers' professional development is fundamental to improving classroom instruction, and it provides a critical pathway for knowledge from pedagogical research to enter the classroom. The clear majority of educational research on the training of teachers comes from schools and not universities. Some of this research looks at the unique expertise of teachers which lies in the intersection of curriculum and instruction and is called "pedagogical content knowledge" (PCK). According to Lee Shulman, PCK

> "goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching […] embodies the aspects of content most germane to its teachability [… including] ways of representing and formulating the subject that make it comprehensible to others" (1986, p. 9).

This description of PCK corresponds well to the German term "Fachdidaktik," which can be translated as the pedagogy of a subject matter.

We know from a large and growing body of empirical studies that teachers' PCK affects their ability to design and implement effective teaching in classrooms. These studies report positive effects of teachers' PCK on instructional quality and in turn, student outcomes (e.g. Kunter, Klusmann, Baumert, Richter, Voss & Hachfeld, 2013; Park, Jang, Chen & Jung, 2010). Relevant to our work with academics, the Kunter study also showed that, in contrast, teachers' general academic ability (a typical strength of university professors) did not affect the impact of their instruction. The Park study connected teacher PCK with their implementation of reform-based science teaching (emphasis on student thinking and learning) and stated that PCK is a "reliable predictor of what a teacher knows and what the teacher is actually doing in the classroom" (Park et al., 2010, p. 254). From large-scale teacher development programs such as the SINUS program in Germany or the global COACTIVE program, we know that pedagogical content knowledge is the crucial part of teachers' competence (Prenzel, Stadler, Friedrich, Knickmeier & Ostermeier, 2009; Krauss, Brunner, Kunter & Baumert, 2008). Based on this evidence from school research we hypothesized that PCK might have a similar effect on teaching in universities.

The exact scope and structure of PCK have long been a topic of debate. Most studies in PCK include elements such as knowledge of subject-specific teaching methods, use of representations, and knowledge of students' understanding of a topic, including anticipating areas of student difficulty. The most current model, the Refined Consensus Model of PCK in Science Education, makes clear that PCK is built from many knowledge bases: content and pedagogical knowledge + knowledge of students, curricula, and assessment. These bases feedback to both one's personal PCK (pPCK), a "cumulative and dynamic" kind of PCK, which acts as a "reservoir of knowledge and skills that the teacher can draw upon during the practice of teaching," and one's enacted PCK (ePCK), the ability to draw on one's knowledge while planning and teaching (Carlson & Daehler, 2019, p. 85). Van Dijk (2009) has shown that the consistent application of the Model of Educational Reconstruction (MER), which enables a critical reflection of the science subject matter and an analysis of the pre-instructional knowledge of students, leads to an expansion of teachers' PCK.

The MER was developed as a "theoretical framework for studies as to whether it is worthwhile and possible to teach particular content areas of science" and it has also been helpful beyond this initial focus (Duit, Gropengießer, Kattmann, Komorek & Parchmann, 2012, p. 19). For example, Niebert & Gropengießer (2013) found it to be a successful model for designing teaching interventions and particularly useful for studying students' pre-scientific conceptions. We used the MER to structure the assignments in TSAU, which ask participants to design an intervention for the content they teach and take into account the knowledge, ability, and interests of their particular student audience. It is important to note that in the assignment we describe in this paper, we have modified the MER's task of clarification and analysis of science subject matter ("Fachlichen Klärung"). Duit et al. (2012) describe the analysis of subject matter as a qualitative content analysis of leading textbooks, key publications, and historical documents on the topic under inspection to analyze the scientific core concepts and the big ideas behind it. As we do not expect our participants to become educational researchers but want them to become (better) educators in science, we broke down the subject matter clarification to identifying the core concept to be taught. We did this in acknowledgement that a broad and historical analysis of the subject matter is too burdensome for someone with regular teaching duties, and that as professional scientists, our participants already spend much of their research time analyzing the publications on the topics they teach.

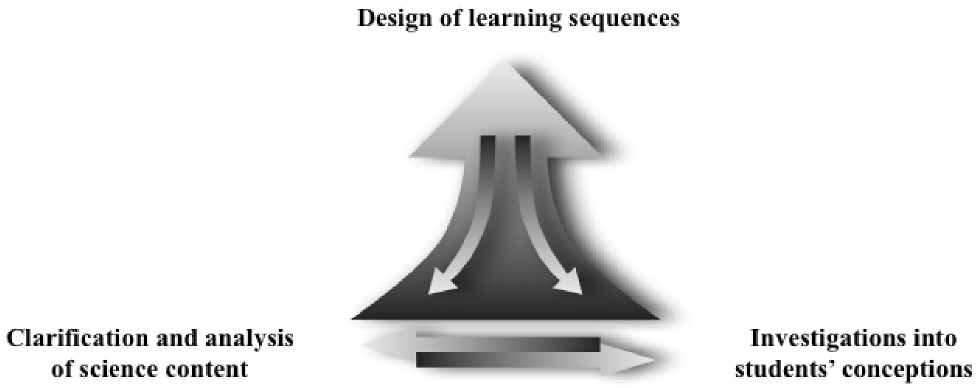

Figure 1: The Model of Educational Reconstruction (adapted from Duit et al., 2012)

3 Our research

3.1 Research questions

The portion of our research presented in this paper looks at the fit and effectiveness of developing university science instructors' PCK with training based on the MER. We simultaneously train and study the participants in our course, and we investigate the following research questions:

(1) How does a professional development course based on the MER influence science instructors' ability to develop student-centered teaching strategies?

(2) How does the course effect science instructors' orientation to teaching?

3.2 Overall course design

We developed our course as an entry point for early career science instructors into thinking and learning about effective teaching at the university level. We built the modules around evidence-based teaching practices described in educational research literature (e.g. Hattie, 2009) and the findings of research on teachers' PCK with respect to designing adequate representations and assignments based on students' prior knowledge (see table 1 on the next page). We focused on research evidence with the expectation that such evidence is how our audience of scientists makes meaning and accepts new ideas. We also expected that our participants have demanding research schedules and limited time; so we focused upon specific teaching tools and strategies rather than broader teaching and learning theories, and we also avoided using too much "educational" language. To ensure active learning, relevancy, and application of knowledge, we designed assignments in which participants adapt strategies from the weeks' lessons to their own teaching contexts and anticipate student response to the new style of teaching.

Table 1: Contents of modules

Week 1	Evidence-based science teaching, how the brain computes information, and key educational theories
Week 2	Conceptual change and the role of student everyday conceptions
Week 3	Teaching with analogies and multiple representations
Week 4	(Re-)Framing science teaching with socio-scientific issues, active learning
Week 5	Teaching science through inquiry in the lab, digital simulations, nature of science

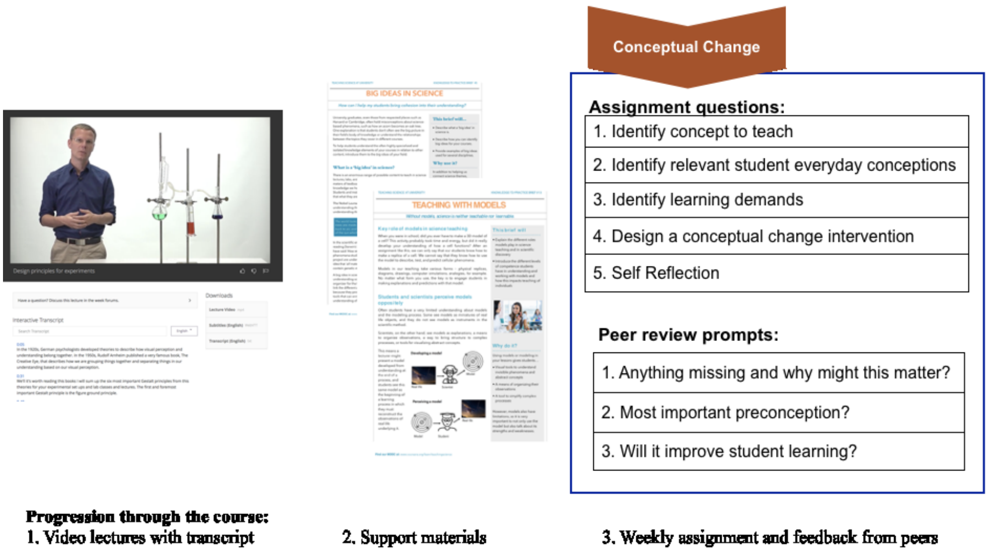

Figure 2: Structure of modules

3.3 Two formats – two cohorts

We offer the course in two formats: as a massive open online course (MOOC) which is open to a global audience via the MOOC platform, Coursera, and has been joined by 2,200 participants (as of Feb. 2020). Secondly, we offer it as a "blended" course, meaning that there are both in-person and online course components. The blended course is available to science PhD students at our university. Both versions of the course involve the same 5-week online materials in which participants watch short instructional videos, use course readings and informational handouts, complete online assignments, and peer review the assignments of others. In the blended course, participants additionally meet in-person for two half-day course sessions. The first takes place at the beginning of a semester and introduces participants to the challenges of teaching well in higher education and to each other. The second takes place at the end of the semester after the online portion has been completed. Typically, participants in the blended course also do some teaching of their own during this semester; thus in the second in-person session, participants share reflections about what new techniques they tried in their own teaching, how their teaching went in general, and how their views about teaching have changed.

3.4 Research methodology

To focus our analysis, we used the second module on conceptual change as a case study. The module can be accessed here: www.coursera.org/learn/teachingscience. It aims to facilitate a critical learning step in course participants – from a teacher-centered, information-transmission conception of teaching towards a student-centered way of teaching based on students' prior conceptions. The module guides participants to develop a conceptual change intervention using a five-step formula we developed based on the principles of the MER. We acknowledge that some consider the term *conceptual change* itself to be outdated, since it is usually not a simple change, but rather a complex reconstruction process that must take place (e.g. Kattmann, 2005). We still stick with this terminology in order to be consistent with the research field.

We know from the post-course survey and participant reflections that conceptual change is largely new to participants, which gives us a chance to see how they learn something for which our course is their primary source of personal development on the topic. We use qualitative content analysis to look at the open-ended text responses produced by the participants in both the assignment and peer review process at the end of week two. In total, we analyzed 63 participant assignments: 35 from participants in the MOOC running on Coursera since January 2019, and 28 from participants in the blended courses at our university in the fall of 2018 and spring of 2019.

For this analysis, we built deductive, evaluative categories with two levels of sophistication. The first is based upon the conceptual change literature (Duit & Treagust, 2003; Strike & Posner, 1982). With regard to the limited time resources of our participants, we concentrated their assignment on selected, pragmatic core aspects from conceptual change research like the importance of addressing students' prior conceptions (Duit et al., 2012), the cognitive conflict (Limón, 2001), and different ways to help students reconstruct their conceptions (Niebert & Gropengießer, 2015; Kattmann, 2017). In our analysis, we looked for the inclusion or exclusion of specific aspects important for a conceptual reconstruction: were students' preconceptions considered? How has a cognitive conflict been initiated? How was further learning of students initiated? Our analysis did not attempt to evaluate the science-specific content structure of each phase, because the assignments come from a vast range of disciplines (e.g. astrophysics, human medicine, theoretical chemistry, etc.). It would go beyond our level of expertise to evaluate, for example, if the student preconceptions identified are the *most important ones* for the given topic. Instead, we simply identified if the preconception was thematically related to the participant's chosen scientific topic.

In the second level of evaluative categories, we used Niebert's and Gropengießer's 2015 framework for designing theory-based, content-specific interventions. In the center of the analysis were strategies to lead students into a cognitive conflict and strategies for subsequent instruction to initiate conceptual development. These categories added depth to our analysis by allowing us to analyze the *type of teaching* planned in the assignment as an indicator of quality, depth of understanding, and PCK. For example, here we considered participants who attempted to generate cognitive conflict by facilitating an experience (e.g. inquiry-based lab work, exploration of raw data, watching a descriptive documentary) to demonstrate a higher level of PCK than those using traditional transmissive teaching (e.g. lecturing, showing answers).

Limiting our analysis to the specific, evaluative categories as described here ensured consistency, accuracy, and reliability in our analysis. Three coders were involved in the analysis. The first author and first coder evaluated all 63 assignments. The second coder analyzed 11 of the 63 assignments (17 %) and had an interrater reliability of 0.80 with the first coder. The third coder was an expert in conceptual change research and only analyzed the fourth question of the assignment where participants were asked to develop an intervention to initiate a conceptual development of their students. This coder analyzed 16 of the 63 assignments (25 %) and had an interrater reliability of 0.88 with the first coder. The materials from our participants we present in this paper are chosen by way of anchor-examples.

Lastly, we used a pre-course survey to assess participants' teaching experience, level of prior training, orientation to teaching, and sense of confidence about teaching. In addition, we used post-course surveys in which we repeated the queries on effective teaching and confidence and asked for feedback about the course as a whole. All participants in the blended course completed both the pre- and post-course surveys (n=37), and we are able to compare individual pre-post results in this cohort. Only a small fraction of the MOOC-only participants completed the pre- and/or post-course survey (pre n=61, post n=25). We have no ability to track these participants in the survey due to data protection, so we are not able to assess individuals' change over time.

3.5 Design of the conceptual change module and assignment

We chose to devote an entire module to conceptual change due to the significance it is assigned by educational researchers. Duit and Treagust (2003) suggest science learning must involve conceptual change, a notion supported by Vosniadou (2007):

> "In order to understand the advanced scientific concepts of the various disciplines, students cannot rely on the simple memorization of facts. They must learn how to restructure their naive, intuitive theories based on everyday experience and lay culture. In other words, they must undergo profound conceptual change" (p. 47).

As for the format of the module, research on how teachers develop pedagogical content knowledge tells us that due to the "highly topic, person, and situation specific" nature of PCK, any professional development program aiming to develop participants' PCK needs to include "opportunities to enact certain instructional strategies and to reflect, individually and collectively, on their experiences" (Van Driel & Berry, 2012, p. 27). We used these three elements in our design of the participants' experience in week two:

- ENACT: The module consists of six videos of around eight minutes each of which focuses on how to guide students into a cognitive conflict and help them develop a more adequate conception. At the end of instruction, the participants immediately apply their learning and design a conceptual change intervention, which we have structured with the MER to teach a topic from their field. In the assignment, they are asked to reflect about the scientific conception, identify their students' everyday conceptions based on literature and prior experience, analyze the learning demand and develop the intervention (see fig. 3 on the next page). We designed all five assignments of the course around authentic tasks in this manner based upon the idea that teacher learning is optimized when it is grounded in a real situation using content from their teaching practice (Putnam & Borko, 2000).
- INDIVIDUAL REFLECTION: The final questions of each assignment focus the participant on reflection: how is the teaching they have described in this assignment different from how they normally teach or how they were taught as a student (keeping in mind many participants have little-to-no teaching experience)? And how will they know if their teaching intervention will lead to improved student learning? These questions give us insight into the participants' prior practices, change process as a result of our course, and their overall pedagogical reasoning.
- COLLECTIVE REFLECTION: After submitting an assignment, participants then read and review the work of two peers. Their task is to act as a "critical peer," looking at the clarity and likely effectiveness of the teaching plan as well as anticipating what would work well or be problematic for student learning. We train participants in the process of peer review, as it is a unique opportunity to give and receive diverse feedback on one's teaching ideas and plans. We emphasize the positive role of peers based upon research showing strong professional learning communities foster learning and improvement of teacher practice (e.g. Borko, 2004).

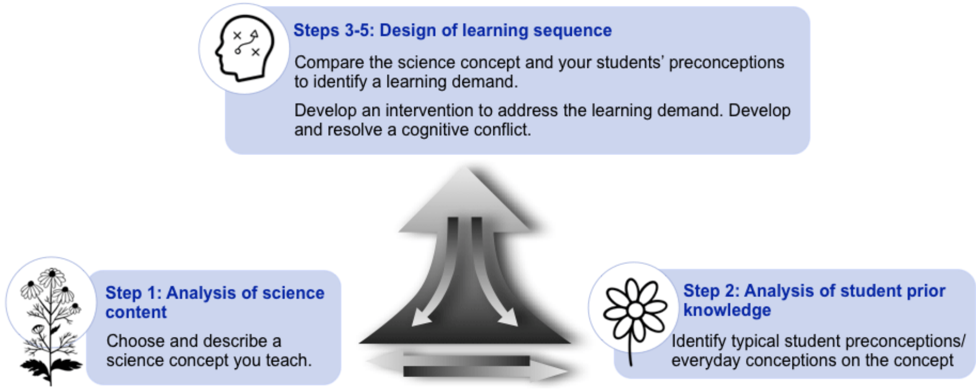

Figure 3: Conceptual change assignment structure

4 Results

4.1 Participant heterogeneity

First, we want to give a more complete description of the scientists who take our course and the differences between the cohort in the blended course on our campus and the global cohort who participate only in the MOOC. We saw from the pre-course survey that these two groups of participants vary significantly. The "Blended-MOOC" cohort are PhD students from our university, are participating voluntarily, and are predominantly women. They have little teaching experience, little pedagogical training, and are generally less confident in their teaching than the participants in the "MOOC-only" cohort. They are a relatively homogenous group compared to the other cohort; they represent many different nationalities and science subject backgrounds, but all work and teach in the same university, mostly in the same faculty of science. Additionally, their participation earns credit they need for completing their PhD. This cohort has the chance to meet one another in person, and we work hard to develop a sense of *esprit de corps* among them, as it improves the effort and empathy they invest in the peer review process.

The MOOC-only cohort is a more equal mix of men and women, with more diverse teaching roles: school teachers, PhD students, early career professors, and experienced professors. They have substantially more teaching experience, training, and confidence. Theirs is an extremely heterogeneous group: diverse nationalities, different institutional cultures, broader ranges of ages and occupations. They earn no credit from our university, but those who finish the course tend to purchase a certification of completion from the online platform, which they use to earn (continuous) professional development credits in their home institutions. Due to data protection laws and requirements of anonymity, we cannot know if the MOOC-only participants who completed the assignments also completed one or both of the surveys.

Table 2: Comparison of the two course cohorts

	Blended-MOOC (BM) (%)	MOOC-only (MO) (%)
	in-person sessions + online course	only online course
Teaching Experience:		
None	26	9
1–2 years	71	29
3–5 years	0	29
6–10 years	3	13
> 10 years	0	20
Teaching training:		
none	85	50
1–2 courses	15	38
teaching certificate or degree	0	12
Most common teaching role:	teaching assistant in practical courses	lead instructor and course designer
Gender:		
Male	23	40*
Female	77	60*
Pre-course self-assessment: Very confident to …		
teach in front of an audience	18	63
manage students of varying ability	3	28
Sample size		
Pre-course survey	n=39	n=61
Assignment analysis	n=28	n=35
Post-course survey	n=29	n=25

* Estimation based upon participant user names on the online course platform.

4.2 Participants' orientation to teaching

Despite their differences, the two cohorts of participants showed a striking similarity in their beliefs about teaching at the start of the course. They were asked to rate 11 different aspects of teaching as "vital," "somewhat important," or "less important." Each group ranked "explains clearly, uses examples and analogies" the highest, with 97 percent of participants in each group choosing "vital." And both groups rated "asking students about their prior learning" as least vital, and by a large margin. Only 39 percent of MOOC-only and 28 percent of Blended-MOOC participants ranked this as vital. It is important to note that in the setup of the question, one could have marked all 11 aspects as vital; this was not a ranking exercise.

The post-course survey repeated the question about what makes someone an effective teacher. Both cohorts continued to rate the ability to explain clearly as absolutely vital. The biggest changes occurred in the aspects of teaching related to students; for example, “Asks students about their prior learning” was deemed vital now by 70 percent of all participants, a jump of around 40 percent. This particular pre-post survey difference is statistically significant in the Blended-MOOC cohort (p = 0.016).

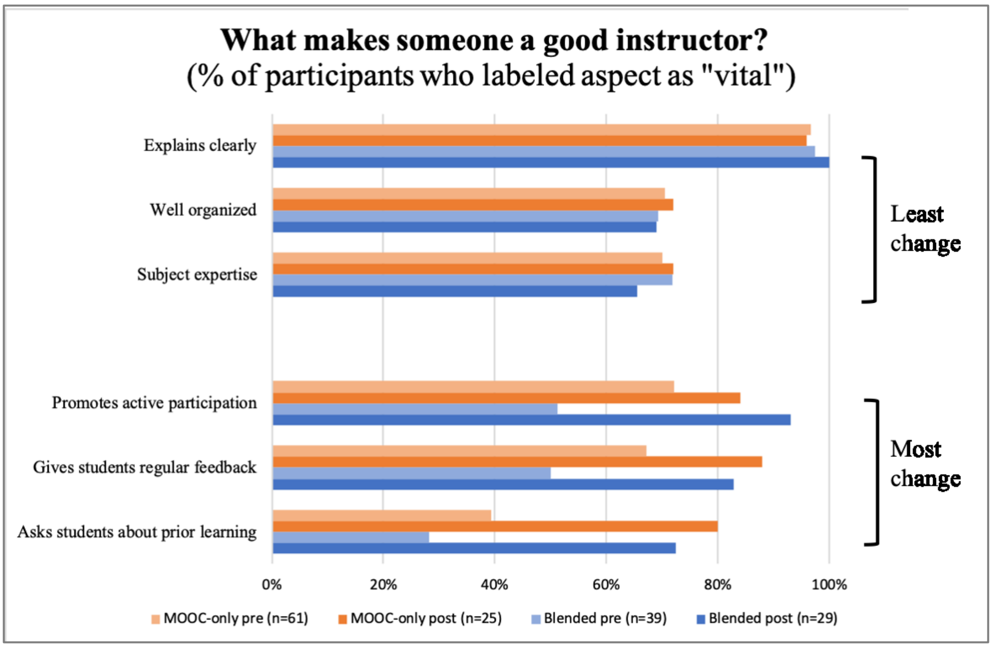

Figure 4: Course participants’ changes in orientation to teaching

4.3 Analysis of the MER-based assignments

4.3.1 Participants’ analysis of science subject matter

As mentioned before, a major task within the MER is the clarification of the science concept to be taught. In research projects, this is done by reflecting upon different perspectives on the concept, looking at its historical origin, searching for everyday conceptions in the literature, and looking for underlying technical and basic principles. Recognizing that our participants do not want to do educational research, are new to educational training and have limited time to prepare their teaching, we broke down the analysis, and asked participants to identify the scientific core concept behind the content to be taught. Participants were encouraged to pick a topic from their curricula that could be addressed in one teaching session and narrowed in on a “teachable grain size”: not too broad, e.g. evolution, but specific enough to be addressed in a single intervention, e.g. adaptation. 87 percent of participants picked a topic with an appropriate grain size and were able to formulate the content to be taught on the level of core disciplinary concepts. Examples include: *bacteria show cooperative behavior, epidemiology differentiates necessary and sufficient causes, paired T-tests analyze significant differences between groups, covalent bonds involve the sharing of electrons between atoms with similar electronegativity*. Some participants (13%) chose topics, which were too broad: *mutations, scientific lab work, organization and systems, or complexity and interplay between diseases*.

4.3.2 Participants' investigations into student conceptions

Participants next considered the preconceptions of their students in relation to the science concept. We wanted to know *if* participants could describe fundamental aspects of their students' prior knowledge, which are relevant to their intervention. We also wanted to know *how* participants determined student prior knowledge. Did they consult educational research as suggested in the assignment? Did they rely on their own experience or that of colleagues? We wanted to see what kind of evidence early career instructors might rely upon.

Nearly all participants (95 %) described a student preconception related to their science concept, but due to the large variety of topics and scientific disciplines represented in the assignments, we were not able to analyze if the described preconception is the *most* relevant one for each topic. The type of evidence cited ranged from generic phrases such as, "most students think …" with no corroborative resource (31 % of participants) to the relative few (9 %) citations of academic literature or internet sources like YouTube or a University Teaching and Learning Center homepage. 45 percent of the participants referred to own or colleagues' experiences and 15 percent identified the preconceptions in discussions with their students in lectures or lab classes.

We saw a clear distinction in the answers from experienced versus novice instructors. The less experienced Blended-MOOC cohort (BM) mostly relied on recollections from their experiences as students. An example from chemistry had to do with the position of electrons in covalent bonds, *"I remember from my first semester of chemistry classes that, for everybody there, this misconception was one of the hardest things to change."* (BM14) The MOOC-only cohort (MO) made no references to their student experience and often based their answers upon their own teaching experiences, for example, *"I have seen it many times in the textbook and heard students talk about it many times in office hours."* (MO22) Generally, participants were able to identify student preconceptions, and some attempted to explain why the preconception exists or why it was problematic (examples in table 3).

Table 3: Examples of student conceptions described by participants

Identified preconception	Movement in a gravitational field: *"The mass of a falling object influences velocity."* (MO5) Sensitivity and specificity in clinical experiments: *"(Students) think of them as feelings rather than a measure."* (MO13) Statistics: *"Paired t-tests are often used to not only compare two but several more group means."* (BM10)
Identified preconception and source	Phototropism: *"The plant is seeking the light. Somehow, the plant knows beforehand that there is light out there and wants to get it. I've experienced the typical thinking that is biased toward anthropocentric thought."* (MO30) Ovulation in mammals: *"[...] the students' main preconception regarding ovulation and fertilization of the egg cell, is that an egg cell can be fertilized by more than one sperm, and that is how identical twins are born [...] This preconception is the most logical and easiest way to explain it. Since multiple ovulation in humans is an uncommon occurrence, students are not acquainted to this idea [...] And their thought process makes them conclude, without evidence that all mammal animals are like that."* (MO33) Causation in epidemiology: *"In everyday life, we use causal vocabulary to describe various non-causal association. The use of such vocabulary carries over in an epidemiology class [...] and can hinder students' understanding of epidemiological concepts."* (BM7)

4.3.3 Participants' identification of the learning demand

In the next step of the assignment, participants compared the scientific concept and student conceptions and based on this, developed specific learning demands to address with an intervention. We wanted to know if participants could identify the gap in perspective and knowledge between a novice/student and an expert/scientist and formulate a learning demand that is both relevant and achievable in a single intervention. The described learning demands fall into three different categories:

(1) Identification of the learning goal, for example, *"students need to comprehend the fundamental differences between association and causation"* (BM7); *"students need to understand that bacteria have no motivation"* (MO6).

(2) Identification of start-point and learning goal, for example, description of the shift in understanding students needed to make: *"The students should change their view from the 'one gene – one function' idea to understanding that one gene is often involved in many functions, and one function often arises from many genes"* (MO21); *"students need to see that populations can evolve not only by being forced to adapt but by chance" (BM4)*.

(3) Abstract description of learning demand: Some participants only demonstrated PK (pedagogical knowledge) and focused on what the instructor should do rather than what the student should be able to do, for example: *"Depending on the outcome of the questionnaire I would know how to tackle the question […] If majority of the class would disagree with it, then I would know that I can present more complex material"* (MO9). Participants like MO9 not only answered without specificity to the scientific topic but also missed the idea that the conceptions of all students, including the minority, should be addressed in teaching.

Overall, most participants (90 %) wrote a learning demand which was related to their scientific concept; however, the vast majority only identified a learning goal based on the conceptions. Only 10 percent just made abstract statements (i.e. category 3).

4.3.4 Participants' design of learning sequences

The final steps of the assignment were to design a conceptual change intervention, ideally including a cognitive conflict. We wanted to know if participants could design a learning intervention according to the principles of conceptual change, which directly addressed the learning demand they had identified. We wondered to what extent the interventions would show the topic- and student audience-specificity characteristic of PCK. And we were particularly interested to know if and how participants included cognitive conflict, as well as the type of teaching described throughout the intervention.

Nearly all (91 %) of participant interventions showed the subject and audience specificity of PCK. Half of participants explicitly included cognitive conflict as evidenced by phrases such as *"counter examples"* (BM6), *"they will quickly realize by themselves that this is not possible"* (BM12), *"their preconceived idea is challenged"* (BM19). Around half of the interventions involved transmissive or instructional teaching to set up the cognitive conflict, for example, a presentation of how antiviral treatments treat viruses when viruses are not alive in the first place (BM4) or explaining an experiment involving electron spin the basis of which is not congruent with students' preconceptions (MO25). Around 40 percent facilitated an experience for students such as *"dissecting what appears to be a simple flower to find out it was actually a composite of multiple flowers"* (BM1), *"plotting a data set multiple times with different statistical tools and coming to a counterintuitive result"* (BM10), or *"analyzing experimental results to form a hypothesis about how hair color is inherited"* (MO21).

Generally, participants focused more on the start of the intervention, sometimes achieving a cognitive conflict and other times likely just getting students' attention to the topic. Participants usually did not describe how they would present new information afterwards with equal detail. Overall, about two thirds of participants described transmissive or instructional teaching to present new information following the cognitive conflict event (if there was one). Some facilitated an experience (around 15 %) and very few used a reflection tool such as a model or analogy. In many cases, the style of teaching was not clear or specified (around 15 %).

4.3.5 Participant reflection

At the end of the assignment, we moved away from the intervention itself and asked the participants to reflect upon their planned intervention. When asked if this style of teaching was different from how they usually teach or how they were taught as students, 65 percent of participants reported that the teaching they described in this assignment was different, for example:

> *I have never been taught by being presented with a conceptual conflict. I think this strategy has a really interesting way of encouraging the students to think about what they already know and the new concept that is being provided to them. I would like to apply this in my future teaching* (BM5).

Some participants focused upon a particular aspect of conceptual change teaching that was new to them and shared their insights about its role or importance in learning:

> *I never thought of using preconceptions [of] students to define their new learnings. As a student, I was always given facts and concepts without much relation to daily concepts like here. This may be the reason why I seem to forget most of the things that I learned in the past* (BM19).

5 Discussion

5.1 The value of MER in higher education

The MER has become a widely used model for educational research and has informed the evidence-based development of teaching and learning in (mainly secondary) schools immensely during the last years. However, questions remain: is the model suitable as a tool for the development of interventions for teachers with (daily) teaching duties and is it suitable to inform the teaching of science in universities as well? At the most basic level, our data show the conceptual change module was effective in conveying knowledge about how and why it is important to build one's teaching around not only scientific content but also the prior knowledge of students. The large percentage of participants who reported never having taught or been taught via a method which explicitly considers the students' perspectives or involves a design for a reconstruction of conceptions means they had little modelling of this good practice before our course. Our data also show that the module assignment based on the MER enabled the vast majority of our participants to apply the design principles of the Model of Educational Reconstruction, and from their reflections, we saw that they found value and purpose in such student-centered teaching.

Going into details, the overall success of participants in narrowing down scientific content to an appropriate grain size for teaching is an important prerequisite to designing specific, focused interventions, which take the time to dig into a single difficult concept. Most of our participants were able to describe the related big science concept or the basic principles underlying the content they are asked to teach in their curricula. This is an important learning step to get participants moving away from standard university lectures, which are packed with factual detail and can lead to surface-level student thinking and rote memorization. It was also clear that participants took time to think about student everyday conceptions. Many showed the extra effort to "look into the heads" of their students, offering hypotheses of why particular preconceptions exist. These participants took preconceptions seriously, which could mean they will be more likely to deal with future students' misunderstanding, with further investigation into prior knowledge rather than labelling it as a lack of effort or ability.

An area for course improvement comes from the fact that very few participants consulted literature on preconceptions from science education research. This indicates to us that the standard of evidence participants apply in their teaching is different from that which they apply in their disciplinary research. However, many participants also reported that giving formative feedback was new to them, and they felt that it was one of the most important take home lessons of the course. Many tried out formative assessment techniques in their assignments like "think-pair-share" and "predict-observe-explain," which had been introduced in the course videos. If tools like these could help participants begin to seek, collect, analyze, and use student learning data in their teaching, we believe the disparity in how they treat evidence in their teaching versus research could decrease.

Looking at the intervention itself, we noticed that the way in which participants crafted a cognitive conflict into their interventions (or not) was probably the strongest indicator of their development of pedagogical content knowledge of any of the parts of the assignment. It was certainly the focal point of participants' effort in the intervention design, sometimes to a fault. Some interventions stated that students would experience a cognitive conflict, when in the end the teaching was more likely to result in piqued student interest, but fell short of the compelling dissonance, which would drive students to rethink their preconceptions on the topic. As the last step of the intervention, participants were asked to solve the cognitive conflict and help students develop an adequate conception. In the best cases, we saw interventions designed to offer students an active learning experience, such as observing the behavior of falling objects to learn about movement in gravitational fields (MO5) or exploring data with an intentionally wrong tool to learn the limitations of paired t-tests (BM10). These demonstrate the kind of teaching most suitable for letting students think themselves into a corner. And here is where the development of PCK really showed: creating such a student experience requires deep understanding of the science concept and science teaching, i.e., not just knowing how to set up a lab, but how to set it up to fail such that it achieves a state of compelling dissonance in students' minds.

In the interventions, we saw consistent differences between the younger, less experienced Blended-MOOC cohort and the older, more experienced MOOC-only cohort. The blenders made more of an effort to try out cognitive conflict. We can only guess why – is it because they have fresher memories of the student experience in traditional, information-transmission lectures or a sense of urgency to change university teaching practices? Is it because they have not yet developed their repertoire of lessons and might as well apply something new? MOOC-only participants tended to answer this question with a description of a complete teaching plan, with indicators that had been used before. They were often less explicit about how students would respond or when they would sense confusion or counter intuitiveness, which left it up to the coders to decide if cognitive conflict was implied, but just not fully described (a limitation to our study, for sure).

Alternatively, perhaps the difference in the cohorts' performances could stem from their differences in teaching experience. Some research shows that in-service teachers can base their teaching practice on their experience, knowledge, and habits, and resist change when confronted with contradictory practices presented in professional development events (Kennedy, 1999, 2016). Another obstacle might be the institutional culture of universities. The prioritization of research preeminence and publications at least at research-intensive universities often means there is insufficient reward for good teaching or incentive for developing as an instructor. And in the absence of training/intervention, university instructors can fall back on the influential "knowledge transmission" mode of teaching, which was modeled by their own professors. This can establish a conception of university teaching, which is "likely to be more deep-seated than student conceptions of scientific phenomena" (Kember & Gow, 1994, p. 71). The take-home message here is that a course like TSAU seems to work best for participants who are still developing or reflecting upon their orientation to teaching and actively expanding their repertoire of lessons and pedagogical techniques. Faculty developers in higher education would describe these ideal participants as those instructors who have not fully developed routines in their teaching, but rather "enter the more hidden but also more rewarding cognitive domains and ask questions about what student actually learn and how they can influence this through their own actions" (Roxå & Marquis, 2019, p. 349).

5.2 Reorienting instructors' focus onto students via the MER

Looking at participants' self-reflection in the assignments and surveys, we saw descriptions of changing teaching skill and orientation. Some participants said their new style of teaching in the conceptual change assignment would push students to think more critically, for example,*"When I was taught these concepts, I was not led into a cognitive conflict with the bigger picture of the gene-concept. I learnt different concepts about molecular genetics but I did not realize that they had a bigger impact about what genetics is"* (MO23). Others focused on the improvement in interest and engagement of students, for example, *"Founding explanations of new concepts on the everyday concepts would surely increase the interest and engagement of students*" (BM6). In these statements, we see a positive influence of the MER's emphasis on balancing analysis of the scientific subject matter with students' conceptions.

If we focus on the similarities of conceptual change and the MER as tools for structuring pedagogical thinking, then the following two points show the most important roles MER can and should play in higher education. First point: participants' reflections showed an appreciation of a scaffold to help structure their preparation for teaching. One wrote, *"I used stories, analogies and few everyday conceptions in my teaching, but I did not know how to use them in a structured way. It is particularly useful [to know] the order in which I should use them for effective teaching"* (MO32). We can corroborate this feeling with our years of experience teaching TSAU as an in-person workshop: early career science instructors seem to appreciate or even prefer concrete, well-structured pedagogical tools – as opposed to more general, abstract theories like constructivism.

Second and most important point: participants saw great value in how the structure of the assignment based on the MER made them take into consideration the experience and prior knowledge of students. This participant says it best:

> *Finding out beforehand what students know is very important and it gives me as a teacher an idea where I should spend more time, whether it is in explaining the basics or concentrate in deepening their knowledge and expand on what the students know already. It was not done when I was a student and sometimes I either felt bored or lost because the material was too easy or too difficult for me to follow straight away. Knowing your playing field beforehand is very important and would ensure that students take the most out of the lectures* (MO9).

In fact, the strongest outcome of the course as a whole is a shift in participant orientation to teaching in the direction of student learning. At the start of the course, participants were asked about an aspect of teaching we called, "asking students about their prior learning," and it must have seemed so out of place that it got the absolute least buy in as something vital to good teaching. Then week-by-week, participants were asked about their students' learning, preconceptions, and everyday experiences. By the course's end, student-centered thinking showed up time and time again in the assignments, peer reviews, and reflections of participants – not to mention its 42 percent jump in "vital"ness in the post course survey. This effect was not just fortuitous; it is the result of the intentional design of the course around the MER. Young instructors may not think of using classroom assessment techniques to poll for student preconceptions because this was seldom modeled to them in their university career. And the longer one teaches, the harder it is to remember first-hand the student experience and student perspective. The MER makes a structural obligation to balance one's planning of content with informed consideration of student everyday conceptions and preconceptions, and we think this is a solid first step to improving the quality of teaching in higher education.

6 Conclusions

Scientists are busy professionals who were typically taught during their own time in university via information-transfer styled lectures and who work in institutions where the vocabulary used about teaching as "requirement," a "load," a "service," does not convey the sense that teaching is given the same priority as research. Nevertheless, we have found that early career instructors, especially PhD students, are very receptive to the evidence-based, science-specific pedagogical concepts and student-centered approaches to teaching at the heart of teaching science at University. We have found evidence of development in the pedagogical content knowledge of our participants, and we have feedback that our course is both efficient and highly relevant.

Our analysis has also shown that our scientist participants very successfully understood and used the structure of the conceptual change assignment, which we designed, based upon the Model of Educational Reconstruction. Though they were not taught about the MER itself, they showed appreciation of its logical way of sequencing teaching and emphasis on the perspective of the students. It is one of the greatest successes of our course to see the change in participants' treatment of student prior learning.

Of course, teaching is not only a profession but also a science relying on theory and evidence. However, science lecturers in universities are usually hired and rewarded for their success in research and not in teaching. Therefore, pragmatic approaches are needed to equip them with strategies to improve their teaching. Based on our analysis, we want to suggest a generic five-step approach for teaching based on the idea of student-centered teaching (see table 4).

Table 4: The five-step MER approach for daily teaching practice

Before teaching	Analysis of science content	Break down the science content to its core concepts. Focus on one concept for a specific intervention.
	Analysis of student prior knowledge	Analyze your students' main preconceptions using literature, own experience, own evidence, estimations based on prior modules, etc.
	Analyze the learning demand	Compare the analyzed science content with the students' preconceptions. Consider not only where the conceptions differ, but also where they match. Determine appropriate learning demands for students.
While teaching	Develop a cognitive conflict	Facilitate an experience that guides your students into a cognitive conflict. Avoid just presenting the not-adequate conception.
	Solve the conflict	Facilitate an experience that helps your students develop an adequate conception. Accompany this by presenting concepts to help your students to make sense of their experience.

We are aware that there is no silver bullet for good teaching, no one-size-fits-all approach. But we propose our five-step formula as an entry point for lecturers with limited time resources and regular teaching duties to develop a clear perspective on science content and to take care of students' conceptions. A generic, recipe-like approach like this could also be a way of using the MER not only as a research design for school science, but also as a strategy for teachers to implement the model into their daily preparation for teaching.

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German Information

Titel: Die Didaktische Rekonstruktion als Modell für die Weiterentwicklung der naturwissenschaftlichen Lehre an Universitäten: Erkenntnisse aus einem Online-Kurs für junge Lehrende an naturwissenschaftlichen Fakultäten

Zusammenfassung: Die Quote an Studienabbrecher*innen in den MINT-Fächern ist hoch. Als Hauptgrund für den Studienabbruch wird häufig eine unzureichende Qualität der Lehre genannt. Eine Herausforderung ist, dass für Hochschuldozierende die Lehre weniger im Vordergrund steht als bei Lehrenden an Schulen, sodass die Vermittlung naturwissenschaftsdidaktischer Kompetenzen für die Lehre für die jeweilige Situation angepasst werden muss. Der Beitrag stellt mit dem Kurs „Teaching Science at University" ein Weiterbildungsmodul für Hochschuldozierende vor, das gezielt auf die Vermittlung naturwissenschaftsdidaktischen Wissens ausgerichtet ist und auf dem Modell der Didaktischen Rekonstruktion (MDR) als Rahmen für die Gestaltung von Lehre basiert. Die Kursteilnehmenden sind Nachwuchswissenschaftler*innen (Doktorand*innen bis hin zu Tenure-Track-Professor*innen) mit großem Fachwissen, aber geringer pädagogischer Ausbildung. Um die Effekte des Kurses zu beurteilen, wurde der Umgang von 63 Teilnehmer*innen mit den Lernvoraussetzungen ihrer Studierenden vor und nach dem Kurs (n=100, 54) erfasst. Es zeigt sich, dass der Kurs zu einer höheren Wertschätzung studierendenzentrierter Lehre und insbesondere zur vermehrten Berücksichtigung des Vorwissens der Studierenden führt. Die Mehrheit der Teilnehmenden des Weiterbildungsmoduls war auf Grundlage des Kurses in der Lage, Interventionen zu planen, die die Lernvoraussetzungen ihrer Studierenden adressieren, die Elemente einer auf den Prinzipien des *Conceptual Change* beruhenden Lehre zu planen und das MDR für die Gestaltung des Unterrichts zu nutzen. Der Beitrag argumentiert, dass eine naturwissenschaftsdidaktische Weiterbildung von Hochschullehrenden eine bedeutsame Rolle bei der Verbesserung der Lehre an Universitäten spielen kann. Wir kommen zu dem Schluss, dass das MDR an der Universität einen nützlichen Rahmen für die Gestaltung von Lehrinterventionen von Lehrenden in den Naturwissenschaften bieten kann. Ausgehend von dem begrenzten Zeitbudget, das Hochschuldozierende für Weiterbildung haben, wird ein pragmatischer fünfstufiger Ansatz für die Einbindung von Kernelementen der didaktischen Rekonstruktion in die tägliche Lehrpraxis an Universitäten vorgeschlagen.

Schlüsselwörter: Modell der Didaktischen Rekonstruktion (MDR), fachdidaktisches Wissen, Dozierende, Hochschuldidaktik, Weiterbildung, Conceptual Change