A progression of pre-service teachers towards deep curricular knowledge (the Pieces model in Open Source Tutorials)

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At the University of Vienna and at Tokyo Gakugei University, we aim to equip our pre-service teachers (PSTs) with “curricular knowledge” about instructional materials, knowledge about the “theory” underlying the curriculum and the reasons behind particular choices such as conceptual flow, use of individual vs. group work, and so on. This study presents two case studies grounded in of our attempts to teach nuanced curricular knowledge about differences between two fairly similar sets of curricular modules. Our analysis centers on two Masters of Science (MS) students who had various experiences involving Open Source Tutorials (OSTs), guided worksheets developed by the University of Maryland. A theoretically nuanced (and hence deep) component of curricular knowledge regarding OSTs is that they are based upon the “Knowledge in Pieces” (in contrast to a “Misconceptions” or unspecified) model of student ideas. The Pieces model maintains that student ideas are not always robustly intact and inherently incorrect cognitive structures, but rather, that student ideas are often temporary coherences of thought assembled from finer-grained pieces of knowledge that can productively be drawn upon and refined in instruction. In our courses, PSTs read research literature about OSTs, conduct mock lessons using existing OSTs, improve existing OSTs, design and teach their own OSTs to real students, and reflect upon the process to further improve the curriculum. Our analysis focuses upon case studies of Brock and Saki, MS students at our institutions. In addition to one-on-one interviews with these PSTs, we will draw upon data from in-class observations and written coursework to discuss how PSTs progressed in their understanding of nuanced curricular knowledge about OSTs and how they differ from some other tutorials.
I. INTRODUCTION

“Curricular knowledge” [1], including “knowledge of the purpose of particular questions” within research-based curricular materials [2], is a valuable component of pre-service teacher (PST) education. Curricular knowledge helps teachers implement the materials in coherent ways [3] and make modifications (if needed) consistent with the underlying approach, rather than following the materials too tightly, failing to deviate in response to unexpected student ideas [4]. Although curricular knowledge is an attainable PST instructional target, it is often not a trivial one [2,5].

In our experience, PSTs come to terms fairly easily with some curricular knowledge, such as why research-based curriculum carves out time for students to articulate and discuss their own ideas. Other curricular knowledge, by contrast, is harder to learn deeply. In this paper, we present an example of such a form of “deep” curricular knowledge and what scaffolding we provided to our PSTs to help them acquire this knowledge. Our aim was to have PSTs come to understand the “Pieces model” of student ideas and how it undergirds Open Source Tutorials.

1.1 Overview of the Pieces model and Open Source Tutorials

Historically, much of PER has focused on diagnosing and “treating” incorrect ideas and ways of thinking that interfere with student learning (e.g., [6]). Researchers have often considered (at least implicitly) these ideas to be stable and almost always considered these ideas to be hindrances to attaining the target content knowledge (e.g., [7–9]); consequently, it has often been argued, instruction should draw these ideas out so that they can be scrutinized and then rejected in favor of the target material (e.g., [10,11]). In 2007, Scherr, building on the work of Hammer [12], contrasted this “Misconceptions model” of student ideas with the “Pieces model”, which explicitly considers student ideas as having the potential to be fluid, with knowledge pieces assembling and disassembling in response to contextual shifts [13]. This distinction is relevant for teachers because it informs instruction (e.g., [14]). Whereas the Misconceptions model typically calls for a confrontation strategy like “elicit, confront, resolve” (ECR) [10,11], the Pieces model calls for instruction where teachers guide students in rearranging the knowledge pieces that they already have—“refining” their intuitive ideas. Many Open Source Tutorials (OSTs) [15] explicitly rely on a “Pieces”-based, intuition-refinement approach. By contrast, many Tutorials in Introductory Physics (TIPs) [16] utilize an ECR approach consistent with the Misconceptions model.

At the University of Vienna (UV) and Tokyo Gakugei University (TGU), we have been instructing our PSTs in the use of OSTs and how they are similar to and different from TIPs. Recently, we have begun collecting data to investigate the degree to which our PSTs understand and appreciate the difference between the Misconceptions and Pieces models. We conceptualize OSTs’ underlying assumption of student ideas being Pieces-like as a type of curricular knowledge [2]. Since the Pieces model and accompanying strategies (like refining intuitions) differ in subtle ways from Misconceptions-based materials employing ECR, we expect this curricular knowledge to be relatively challenging to inculcate in PSTs, and our research questions for this paper are “to what extent is the Pieces model of student ideas an attainable instructional target for pre-service teachers? In what ways can teacher educators support pre-service teachers in coming to understand the model?”

II. STUDY DESIGN AND METHODOLOGY

Our qualitative study draws upon video and audio recordings from in-class discussions in courses for PSTs and from one-on-one interviews with PSTs. Our focal participants come from two cohorts of PSTs, one instructed by the first author at UV and the other instructed by the second author at TGU. At TGU, the second author teaches the large-enrollment course “Physics Exercises” for undergraduate PSTs. OSTs serve as the core to “Physics Exercises” and TA’s who facilitate the OSTs are often upper-classmen PSTs or PSTs in the MS program. TAs meet weekly with the second author to prepare for the next week’s OST, and they meet again after the OST to reflect on the experience. We present below a case study of Saki (all names are pseudonyms), a MS student who took the “Physics Exercises” course as an undergraduate PST in 2018 and then went on to become a TA for the next generation of PSTs in 2021. For her MS thesis advised by the second author, Saki made significant modifications to the Pressure OST and investigated the effects of these modifications. She was interviewed by the second author in May 2022. She was presented with a gift certificate worth $10 to the bookstore as compensation.

In the winter semester of 2021-2022, the first author taught a low-enrollment OSTs-based seminar for PSTs in a MS program at UV. Like at TGU, PSTs at UV experienced a different Tutorial every week, but it was generally done in a mock lesson format. That is, one PST took on the role of “teacher” for the lesson while the other 4 PSTs were “students”. Feedback was provided to the “teacher” after the Tutorial, and the “teacher” then wrote a reflection about the mock lesson. In this seminar, PSTs were also assigned as homework reading about the theory underlying OSTs (including the Pieces model), and the seminar culminated in each PST creating his or her own OST and arguing how it is consistent with the “spirit” of OSTs in that it “expects and utilizes the fact that student reasoning is often fluid (in accordance with the “Pieces model”). Each PST taught their own OST in a high school, usually with about 20 students to instruct alone, wrote a reflection, and improved the OST.
Three of these PSTs (Brock, Arnold, and Sean) were interviewed by the first author in February and March 2022 (after the seminar had concluded and final grades had been assigned). As compensation, the first author donated money to treeenanation.org for trees that the PSTs had chosen to be planted in their honor. Brock, who serves as our second case study below, had been one of 16 PSTs to take an undergraduate version of the OSTs seminar (which did not include the creation of an OST) from the first author in the summer semester of 2018. In between the two seminars, Brock had experienced teaching with OSTs in his own classroom during a year-long internship. All interviews were video and audio recorded with interviewee consent. At UV, each class was also audio and video recorded, and PSTs were assured that the first author would not share this data with the other authors without consent, and that consent forms would only be checked after final grades had been assigned. Interview questions for Brock were based in part on things Brock had said and done in class, in order to further draw out his thinking about the Pieces model and OSTs.

After the course ended, the first author made an outline of the interview with Brock, highlighting and transcribing points that related to Brock’s understanding of and views about the Pieces model. Consistent with the constant comparative method (e.g., [17]), the first author drew upon the transcribed text as well as Brock’s written coursework and in-class utterances to draft an account that was shared with the other two authors. Claims about Brock were scrutinized by looking for consistency across the interview as a whole, and modifications were made until agreement between the three authors was reached. A similar process was carried out in creating Saki’s case study.

III. PSTS CAN LEARN THE PIECES MODEL

At both the undergraduate and MS seminars at UV, the Pieces model is taught to PSTs by contrasting OSTs with TIPS. Since Brock had completed the undergraduate seminar, the first author asked Brock on the first day of the MS seminar what, if anything, he remembered that he could tell his classmates about OSTs. He recalled that they are worksheets originating from research on student ideas that are completed in groups. Brock did not recall any contrast between OSTs and TIPS, nor did he mention ECR or refining intuitions. From this and other evidence, we infer that Brock had learned curricular knowledge about tutorials in general, such as the use of small-group work to elicit student ideas, but had not learned (or at least, not retained) knowledge about “Pieces” and the nuanced characteristics of OSTs.

At the end of the semester, however, Brock demonstrated more nuanced understandings. When asked how he would explain the differences between TIPS and OSTs, Brock responded “TIPS use the elicit, confront, resolve method explicitly, and OSTs don’t use that, and it’s more about epistemology as well, that’s what I would say are the key elements, the key differences.” Before the interviewer explicitly mentioned it, Brock brought up the Pieces model in the interview:

*I think these intuitive ideas... will remain with you almost forever, because they are intuitive... it kind of relates to the Pieces model... more about restructuring them maybe, or adding new pieces to that piece, to previous information or previous intuitions.*

Furthermore, Brock demonstrated in the interview that he saw the value in thinking about student ideas as being something that can be “worked with” instead of “removed”:

*I think it is not worth the time, even if it is, even if [emphasis his] it is possible, to remove all these ideas, but it is better to add additional ideas and to teach students how to, how to work with their intuitions and new physics...*

We see these statements as indicating understanding of the Pieces model, not merely because Brock is able to produce the technical jargon (“Pieces model”) on his own, but because he is able to describe the model without support from the interviewer. He discusses “restructuring” instead of “removing”, a key characteristic of the Pieces model. Brock could articulate that eliciting and confronting misconceptions is not always the best thing to do.

By the end of the seminar, Brock had succeeded in creating his own OST that the first author judged to be consistent with the Pieces model. Figure 1 shows a translation of an explicitly-labeled “intuition refinement” part of Brock’s OST on Heat and Temperature.

![Fig. 1](image.png)

**FIG. 1.** An excerpt from Brock’s OST that he explained came from the “recipe” of refining intuitions.

The difference between the two models is something that Brock came to understand in the MS seminar. When asked “Is there anything specific that you can remember that like, sank in more, or that you understood better the second time around that you had not really picked up the first time?” Brock quickly responded with “I think the difference between OSTs and TIPS. That wasn’t... or it wasn't so clear to me in the first round, yeah. Definitely.”

Like Brock, Saki also advanced her understanding of the Pieces model from the first to second “round”. In the interview conducted by the second author, Saki said that she now finds the approach of refining intuitions to be “really interesting” but that when she was an undergraduate PST learning from OSTs, that she had “probably not really understood it at all.” Now, however, when prompted by the interviewer, Saki was able to identify the process of refining
intuitions in the Pressure OST she was modifying, even though it is not explicitly labeled as such in the OST.

Like, a lot of students catch this rough idea that the magnitude of water pressure has something to do with height or displacement from the water surface... There is where that ambiguity comes in, but when you go through experiments and solve problems, you will find that it is not the amount [of water on top] ... or distance to the ceiling, but the height from the water surface ... that is close to refining intuitions.

Nowhere in the interview did Saki deliver an explicit contrast between the Pieces and Misconceptions models as Brock did, nor did she refer to the ECR process. Nevertheless, in the above quote, Saki discussed how the Pressure OST uses experiments and “problem solving” to make less “ambiguous” the idea that students already have about pressure. The fact that she was able to specify how the OST refines student ideas like this demonstrates understanding of an element of the Pieces model.

Our case study includes only two PSTs, so we aim only to generate hypotheses about whether the Pieces model is a feasible instructional target. Nevertheless, evidence suggests that Brock and Saki were not unique. The other four PSTs in the MS seminar, like Brock, all succeeded in creating a “Pieces”-like OST.

In their interviews, both Sean and Arnold (two of Brock’s classmates) demonstrated an understanding that OSTs see student ideas as containing valuable knowledge pieces that can productively be drawn upon in learning. As such, in answer to our first research question, “to what extent is the Pieces model of student ideas an attainable instructional target for pre-service teachers?”, we have presented an existence proof that it is indeed attainable, but that it requires more investment than the relatively superficial curricular knowledge about OSTs being group-based interactive engagement materials. While this existence proof is an important first step, future work should investigate what percentage of PSTs deepen their curricular knowledge if they receive scaffolding like Brock and Saki did.

IV. FACTORS THAT MAY HAVE CONTRIBUTED TO PSTS LEARNING THE PIECES MODEL

As discussed above, at the start of the MS seminar, Brock did not demonstrate an understanding that OSTs are designed upon the assumption that student reasoning can shift fluidly from moment to moment. This indicates that merely being exposed to OSTs, reading the teacher’s guide, and teaching with the OSTs (which is what Brock did in the first seminar and what most TA’s go through when they receive TA training) might not be sufficient to comprehend the more subtle aspects of curricular knowledge associated with OSTs. What then, led to the growth that we observed in Brock in the MS seminar? Was it simply a second semester of exposure? Indeed, he credited that as giving him “a huge advantage compared to [his] peers” in the seminar.

... I knew most of the Tutorials ... so I could look into them in more detail, and I did know some of the concepts before, so that maybe helped me to deepen my knowledge ...

Immediately prior to this point in the interview, Brock had been talking about the role of models in learning physics and about how people often misapply those models in trying to make sense of their world. After saying the above quote, Brock would next say that he came to understand the difference between OSTs and TIPs in the MS seminar (see transcript in previous section). Based on this context, we think that his saying “I did know some of the concepts before” is not about his understanding of physics content knowledge, like Newton’s laws. Rather, we interpret his statement to be referring to his previous well-developed understanding of tutorials in general, including both OSTs and TIPs, as engaging small groups of students in guided inquiry in order to help them reconsider their ideas. We find Brock’s explanation very plausible: it is likely that Brock’s prior understanding set him up to focus more narrowly on nuances about what “reconsider their ideas” can entail. In addition, Brock gave much credit to the process of creating his own OST. When asked at the beginning of the interview if he felt the seminar would help his future teaching, he spontaneously brought up the creation of his own OST:

...I was thinking on my way here, that... especially, the part of creating materials by yourself I think is really really beneficial for your future practice as a teacher... I think it is kind of the key element of the whole course... kind of the difficult part is thinking about, “ooh, ... how do I deal with misconceptions? in general? Is that such a strong relevant misconception that I have to confront it using ‘confront, resolve’?”

The first author then asked Brock if, even were he never to use the OST he created or teach that specific topic again, he still felt that “it would have been beneficial to have gone through the process of creating this thing.” He responded with “yeah, definitely” and continued with the following explanation, including his recollection of his own OST (see Figure 1):

... it is kind of a recipe... you need to find out whether that recipe works for that different topic, so, like with the boxes model [see Fig. 1], so you are refining an intuition, I used two boxes as well... it is still useful if you know about the methods.

In contrast to just seeing the methods used in other OSTs, Brock emphatically said that “doing it yourself is on a different conceptual level”, and he ascribed to it the greater depth that is generally obtained when actually doing something yourself instead of being shown how to do it.

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1 We will soon submit GIREP 2022 Proceedings from our poster “The Interplay of Curricular Knowledge and Perceived Agency of Pre-Service Physics Teachers in Vienna and Tokyo” that discusses these other PSTs.

2 Throughout the interview, Brock used the word “misconception” as a generic term, as we use the phrase “student idea” in this paper.
Taken together with the preceding transcript, we see Brock as saying that creating one's own curriculum in a given style builds expertise in understanding the "recipe" of that style.

As discussed above, Brock came to understand the difference between OSTs and TIPs in this MS seminar. In particular, in the interview, Brock could articulate the Pieces-based approach of OSTs, and he valued this approach. The process of creating an OST involved receiving feedback multiple times, both from the first author and from Brock's classmates throughout the creation process, and hence occupied a significant portion of the seminar. Brock described making his own OST as being the "key element" of the course, and it is plausible that this helped him come to better understand the Pieces model as he had to answer carefully "how do I deal with [student ideas] in general?"

Unlike Brock, Saki did not create an OST from scratch. Instead, she modified an existing OST. Saki credited not her creative process of modifying the Pressure OST, but rather, her teaching of existing OSTs for helping her come to value the OST-style of instruction. In the interview, she said that she would have more than half of her class time be group-based, and she showed her support for the type of discussion that is emphasized in OSTs:

A lot of students ask me if something is correct or not, but... [it should not be] "the teacher says it is correct so it is correct", but rather, I think it is more important whether that will convince someone or not. ... I want to recognize "ah, there is also that way of thinking about it, I see!", or, yeah, with incorrect ways of thinking, I want to observe where it is that a contradiction is taking place...

When asked if Saki always felt that way, she responded that it was a change that had taken place as a result of being a TA for OSTs. She specified that while doing her best to follow the fast thinking of the students, she would come to wonder how the students were coming up with the ideas that they voiced, and she came to recognize the importance of answering that question. We acknowledge, though, that here and elsewhere in the data, Saki didn’t articulate a Pieces perspective as fully as Brock did. We revisit this point below.

V. CONCLUSION

We have investigated progress that two MS students made in coming to understand the Piece model. To be clear, we do not conceptualize understanding of the Pieces model in a binary (understand or not) sense. Rather, the model has many facets about which learners can understand to varying degree. Saki demonstrated awareness of the importance of having students make sense of the material in their own terms but did not explicitly connect that awareness to the Pieces model. Brock, on the other hand, connected specific instructional strategies like intuition refinement diagrams to the underlying Pieces model.

As an undergraduate, Brock took a seminar on OSTs where he read and heard that OSTs are premised on the assumptions that student ideas are comprised of smaller knowledge pieces that can fluidly rearrange in response to contextual cues. Despite this, and despite having taught with OSTs for a year after the seminar, Brock did not articulate this characteristic of OSTs at the start of the MS seminar. This suggests that the Pieces model and its relationship to OSTs is nuanced curricular knowledge, challenging for PSTs to attain. Nevertheless, we have presented an existence proof that PSTs can reach a deeper understanding of the Pieces model. At the start of the MS seminar, Brock already understood why small-group discussion of conceptual issues is helpful, indicating existing curricular knowledge about active-learning Tutorials. Through his experiences in the seminar, Brock was able to build upon this existing curricular knowledge to develop the more nuanced curricular knowledge demonstrated later in the semester.

By focusing on case studies of Brock and Saki, we have also addressed our second research question: "In what ways can teacher educators support pre-service teachers in coming to understand the model?" Specifically, Brock credited his learning about the difference between OSTs and TIPs (and, by extension, about the Pieces model) particularly to 1) having taken the course as an undergraduate, and 2) creating his own OST. From these two points, we hypothesize that educators wishing to instruct PSTs in the Pieces model should expect to allocate substantial class time to do so, and that devoting time to the process of creating an OST may be time well spent. Saki’s experiences suggest that being an instructor of OSTs plays a key role, too. Scaffolded by weekly TA training, Saki came to recognize the importance of listening to student ideas to find “where it is that a contradiction is taking place” in student reasoning so that students can become personally convinced of the material instead of just memorizing it because “the teacher says it is correct.” Although Saki, unlike Brock, did not explicitly contrast the Pieces and Misconceptions models or discuss ECR, she was able to recognize—on her own—how the Pressure OST refines student ideas about “depth” and pressure, as discussed in Section III. We expect that a PST who is thinking of student ideas only in terms of Misconceptions would have great difficulty doing this, and we find it plausible that listening carefully to students discussing their ideas about pressure contributed to Saki’s awareness of this point.

In this paper, we have chosen to focus on the features of the support we provided that the PSTs identified as salient. Other factors likely played a role as well, and our data greatly underdetermine the fine-grained learning pathways. Still, our case studies suggest that understanding about the importance of eliciting and attending to student thinking is a helpful knowledge base upon which to build more nuanced curricular knowledge about (in our cases) the Pieces model and its curricular implications.