Centering physics faculty ideas about resources-oriented instruction

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Recent research on faculty adoption and adaptation of research-based instructional materials suggests that development and dissemination of such materials should center instructors' productive ideas about teaching and learning and should build on instructors' current instructional practices. We are focussed on the development and dissemination of resources-oriented instructional materials—materials that elicit and build on students' productive ideas. To inform this work, we interviewed 17 physics faculty members to understand their current ideas and practices, and what might make these materials appealing. In this paper, we illustrate three specific themes that we identified in physics faculty members' resources-oriented perspectives of students' ideas and learning. We find that faculty are captivated by the novelty of students' ideas; notice consistencies between students' prior knowledge and physics concepts; and identify contexts in which students' ideas are correct. These themes inform curriculum development and dissemination efforts as well as research-based implementation materials that support instructors in their use of resources-oriented curricular materials.

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I. INTRODUCTION & BACKGROUND

One significant contribution of physics education research has been the development and testing of topic-specific instructional materials [1]. These materials have experienced significant take-up among introductory physics faculty [2]. Research on faculty adoption and adaptation of research-based instructional materials (RBIMs) suggests that development and dissemination of such materials are most successful when they build on instructors' current instructional practices [3], and that curriculum developers should adopt a paradigm that centers instructors' agency and productive ideas about teaching [4].

This paper builds on prior research by examining physics faculty thinking about student ideas, to inform the development and dissemination of RBIMs that are grounded in a resources-oriented (RO) instructional framework. In a RO instructional framework, learning is conceptualized as eliciting and building on *resources*—useful ideas that are activated in a context-sensitive way [5–10]. Resources are not necessarily correct, but rather "seeds of science" that are generative regardless of their correctness [5,6,8,11,12]. Instructional materials and teaching practices based on an RO framework (e.g., [13]) seek to support instructors in making connections between student ideas and the canon by emphasizing the sensibility of students' ideas [7,14,15]. RO instruction asks instructors to be flexible and responsive to what they notice as instruction unfolds [16,17].

Just as resources-oriented RBIMs are based on the assumption that students bring and then activate productive resources for understanding physics [5,7,8], this study assumes that faculty have and activate productive resources in their teaching. Because our focus is the development of RO instructional materials, we sought to identify some of the productive resources that faculty use as they discuss paying attention to and building on students' ideas.

To explore this, we interviewed 17 physics faculty about their instructional practices and how they think about student ideas. Though rarely the primary framing of student ideas that interviewees brought forward, we identified multiple instances in many interviewees' descriptions of their teaching that were aligned with a resources framing. In this paper, we present three themes from interviews: faculty are captivated by the novelty of students' ideas; notice consistencies between students' prior knowledge and physics concepts; and identify contexts in which students' ideas are correct. We interpret these themes as some of the things that *turn instructors' attention toward* student resources and *get them excited about* student ideas. These themes may help RO curriculum developers design and disseminate materials that center instructors' existing ideas.

II. METHODOLOGY

Authors LB and CM conducted 17 semi-structured, exploratory interviews with physics faculty from institutions across the United States. We recruited interviewees with support from the American Association of Physics Teachers, prioritizing community college faculty and participants from previous offerings of the New Faculty Workshop. From a recruitment email, we received 27 pre-survey responses and reached out to all 27 faculty, in two rounds. We aimed to interview a diverse set of faculty along many axes including race, ethnicity, gender, institutional context, familiarity with RBMIs, and teaching experience. In the first round, we prioritized (self-reported) racial and gender diversity, and then diversity in location and size of institution, familiarly with RBIMs, and teaching experience. In total, we interviewed 17 faculty, 9 in the first round and 8 in the second. Despite our attempt to recruit a racially diverse sample, 24 of the 27 pre-survey respondents identified as white, so our pool was predominantly white. This not only limits the generalizability of our findings, but also contributes to a broader trend where the results of PER disproportionately benefit white people [18].

Of the faculty we interviewed: 7 self-identified as female and 10 identified as male; 14 self-identified as white, 1 as African, and 2 did not identify their race or ethnicity. Seven participants had been teaching at their institution for 0-3 years, 4 for 3-10 years, 4 for 10-20 years, and 2 for 20+ years. Additionally, the interviewees came from a variety of teaching contexts: 8 taught at 2-year community colleges; 5 at private higher-ed institutions; and 4 at 4-year public universities. The interviewers, authors LB and CM, identify as a white, Canadian, female, and Black, American, male respectively.

Each interview lasted between 30 and 60 minutes and included questions on topics summarized in Table 1. During the interview, we showed instructors an example of RO instructional materials. The example instructors were shown was a worksheet designed to support students in building models by eliciting and refining conceptual resources. These instructional materials prioritize flexibly engaging students in a process; there is rarely a single, correct answer students are guided toward [19]. The same interview questions were used in all interviews, but the exact wording and follow-up questions varied in response to the conversation with the interviewee. The interview protocol was slightly adapted for the final 6 interviews; two questions were added to make the original protocol clearer; no questions were removed. All the interviews were recorded and transcribed for analysis.

Analysis of the transcripts was iterative: a sub-team of co-authors met for weekly collaborative meetings where individuals brought excerpts to discuss, and then first author LB searched transcripts for additional instances of interest, which were then collaboratively discussed. Initially what stood out was the prevalence of misconceptions-oriented framing among participants; we then noticed subtle hints of resources framings, and this became our analytic focus.

TABLE 1. Summary of interview protocol.

Background information	**Current practices**	**Views on learning, pedagogy & teaching**	**Thoughts about resources-oriented instructional materials***
• Motivations for teaching. • Most enjoyable aspects of the job. • Defining success in the classroom.	• Describe a typical day in your classroom? • Instructional materials currently used. • When in class do you hear students' ideas about content?	• Describe a student's idea you heard in class and how you interacted with it. • What do you find challenging about responding to students' ideas? • Described a theoretical situation and asked: what would you do? • Is it okay for students to leave physics class with an incorrect idea?	• Would you use this worksheet, under what conditions? • What would you like to know to use the worksheet more effectively? • In general, does the format of these worksheets appeal to you? *We showed interviewees a worksheet and asked these questions as follow up.

First author LB then selected interview excerpts that showed faculty using RO framings—which we consider "cases of" [20,21] these framings—and we collaboratively conducted a thematic analysis of these instances [22], identifying the three themes in Section III. The interpretive validity [23] of the themes is enhanced by the collaborative nature of our analysis.

III. RESULTS

In this section, we highlight three ways that instructors discussed teaching strategies and students' ideas that aligned with a RO framework. Each came up in multiple interviews, and we present examples from several participants. Because these were interviews and not classroom observations, we cannot speak to implementation; rather, we claim that faculty bring ideas, opinions, and motivations of teaching and learning that align with RO instruction.

A. Being captivated by the novelty of students' ideas.

This theme captures instances where faculty described novel, interesting ideas they have heard from their students. Interviewees often did so animatedly, expressing their excitement about hearing something they'd not heard before, or learning from their students. One physics faculty, pseudonymed Nadia, told us about an idea she heard in a lesson about the motion of blocks on slopes in her introductory physics course. She described a conversation where a student proposed a different way to think about determining the angles between the forces in a free-body diagram, particularly the angle that the incline makes relative to the horizontal: *"The student that gave me this piece this semester was just really fantastic. He said that if the, if the incline angle went to zero, then this* [pointing to drawing, see figure 1] *would become vertical… I never … thought of it that way. So, he said, then this angle has to be equal to that because this goes to zero, as the incline comes down to be horizontal. And I thought, that's a great way of saying it, you know…I told that student, I said, 'this is really genius, I'm going to use this in future classes to illustrate.'"*

In this example, Nadia shared an instance where one of her students conceptualized similar triangles differently than she did. This example is aligned with RO instruction because Nadia celebrates the sensibility and fruitfulness of this student's thinking—what Duckworth calls "the having of wonderful ideas" [24]. We were particularly struck by her enthusiasm. Beyond just acknowledging that there was more than one correct way to conceptualize the problem, Nadia described her student's idea as "genius" and "fantastic," emphasizing how she, the teacher, learned something new in this exchange. In doing so, there is an implied sense of intellectual equality where the classroom is a place of learning for both teacher and student.

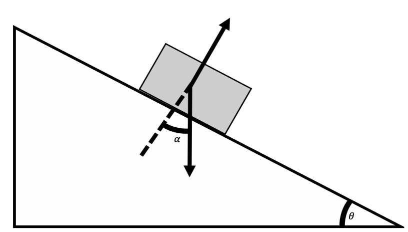

FIG.1. The figure Nadia drew to explain her student's idea.

Nadia's prolonged, detailed discussion about a particular student idea was less common in our sample. However, many faculty commented on instances of their students' wonderful ideas. For example, Keith (pseudonym) described a lesson on lenses, refraction, and optics. When discussing the "water drop microscope," one student connected this to their experience: *"Oh yeah, you know, if I get water on my iPad, I can see the pixels because it acts like a magnifying glass."* Keith thought this was a great example, saying: "*I actually incorporated that into a lab [in the] online environment, because it's something they can do at home, you know, take a drop of water, put it on your iPad, and can* *you see the pixels?"* Like Nadia, Keith shows willingness to take students' ideas up in his teaching, a central value within a RO instructional framework. Both Nadia and Keith described students' ideas that they saw as novel and fruitful [24], which embodies a RO perspective. Further, these instructors indicate how they did or would incorporate these ideas into their teaching. This practice aligns with our understanding that RO instruction takes shape or changes course in response to the resources that students use in the classroom [17] and takes time to notice and enjoy the wonderfulness of student thinking [24].

B. Building on students' prior knowledge to teach physics concepts.

In this theme, faculty articulated consistencies between students' prior knowledge and formal physics understanding and ways they can build on this prior knowledge toward new physics concepts. For example, when asked how he uses students' ideas in his teaching, Paul (pseudonym) described using familiar metaphors to draw connections to physics content: *"I often aim for metaphors to hold up a physics concept, [saying to students], 'this is exactly the same as this other thing with which you're actually really familiar with.'"* He explained the importance of hearing students' ideas as a pre-condition to this strategy: *"It helps to know what the[ir] thinking currently looks like to try to find a metaphor that correctly sort of maps current thinking through to…a more full understanding of the concept."* Drawing connections between students' prior knowledge and physics, as Paul enumerates here, positions the student as having robust physics knowledge and understanding prior to a lesson—a belief that is aligned with RO instruction.

Later, Paul gave an example: *"We were talking about the first law of thermodynamics…By this point, my, uh, sort of content theory is that you [students] already know the first law of thermodynamics, you just don't know that it's called that."* Paul explained that he believes the students in his class intuitively understand the first law of thermodynamics even if they have not yet recognized it as the first law. Paul was the only interviewee that discussed using a metaphor strategy to connect students' prior knowledge physics concepts; however, most faculty commented on their belief that students come to class with prior knowledge that helps them make sense of physics concepts.

Another example of this theme came up in our interview with John (pseudonym). He described how he tries to emphasise how much students already know: *"I try to tell students many times like…how much of this they already know in some kind of like intuitive way; they've all dropped something, all thrown something, they all have like a lot of physics intuition coming into this class. And what we're going to try to do is to try to make that more formal with, you know, equations that can now be more precise about the things that they already know."* For John, recognizing the intuitive knowledge students bring into class is important because it helps make physics less intimidating. He places a lot of importance on: *"help[ing] students feel empowered with the knowledge that they do have and like, recogniz[ing] that as totally legitimate."* A desire to make physics more accessible and create a classroom environment where students feel empowered was a sentiment that the majority of the interviewed faculty expressed. For example, Quinn (pseudonym) explained why she believes it's important to build on students' ideas: "*The more that I can use the--, what they think about a problem, the closer I can get them to believing in their own ability to be able to think about physics problems and whether they're easy physics things or hard physics things, it's something that they can do."*

These instructor statements are consistent with the assumption that students' conceptual resources are sensible and derived from everyday experiences, and that these are the material from which new knowledge is constructed [6].

C. Identifying contexts in which student ideas are correct.

This theme captures instances where faculty described student ideas that would generally be considered incorrect and named ways or contexts in which those ideas are correct. One interview question asked faculty how they would respond to a student who was given the "Airplane Question" from the Force Concept Inventory [25], in which a students are asked to choose the trajectory of a bowling ball dropped from a plane flying to the right. The example student chooses trajectory A (where the ball falls behind the plane), claiming: "the bowling ball falls behind the plane because air resistance acts on the ball, pulling it backward." This response is incorrect: while air resistance can decrease the magnitude of the ball's (forward) horizontal velocity, it cannot "pull the bowling ball backward" or cause the ball to move in the opposite direction as the plane.

This question was designed to help us understand how faculty perceive and respond to canonically incorrect student ideas. John answered: *"Yeah, I would say for sure, air resistance should be important here. Um, how do we, how do we add that? Like, let's think about the bowling ball at the moment that it's released and start drawing in vectors that might represent air resistance and other, other forces acting on it and then let's make a separate drawing with its motion maybe."* Although air resistance does not reverse the direction of an object's velocity (and, in the context of this problem air resistance can be considered negligible), John explicitly validates the student's idea and asks them to incorporate air resistance into their model.

Later in the conversation, we gained more insight into John's thinking when he said: *"...Correct is a spectrum, right? I mean, like for example, with air resistance…you can always add additional complexity to a problem. So, any problem can be really as correct as like the set of assumptions that you're making about it now."* John's reflection illustrates the continuum between correct and incorrect that RO instruction tends to embrace. He doesn't view the student's incorporation of air resistance as an incorrect answer, but rather a sensible intuition that adds complexity to the problem. John not only acknowledges the student's idea as sensible, but also demonstrates a willingness to adapt his instruction—and physics problems—in response to the student.

In another example of this theme, Owen (pseudonym) described an exchange in his class sparked by a student's belief that the force exerted on a car during a collision with a larger truck must be bigger: *"Just yesterday in discussing linear translational style momentum questions...there [was] a student who really wanted to defend the…statement about…the car and the truck colliding. 'The truck wins because it's bigger' and they really wanted to defend that. And…so I said, 'Well, why does that matter? Why does that size matter?' He said, 'Big mass.' Well, what is it about the mass? He said, 'Oh, well, it's, it's, the mass is related to the, to the force, F=ma.' And I said, 'Well, yeah, kind of, but, but why, why is that? How does that matter for the outcome of the collision?' And he says, 'Well, the car gets all messed up because it's less massive." And I said, "that's, that's after the whole collision.' And somebody says, 'Oh yeah, that's after the collision,' and they started to talk a little bit."*

In this exchange, Owen engages with the student's idea by asking follow-up questions that encourage students to consider the collision at a different instance in time. He continued: *"…the outcome that physicists are worried about is different than the outcome that the general populace is worried about. The general populace wants to know, did my bumper fall off? Do I have to take this to the body shop? Where physicists are much more concerned with, well, how fast did it—? How bouncy was it? And how fast did it move away? Or did these things stick together? You know, we're…looking at it in that…very limited, uh, momentum model idea. It was a learning experience for me to highlight that we're applying this model to something that happens very, very quickly. That collision lasts less than a second, and that's all we're concerned with. We don't really care if the bumper flies off afterwards, that's not part of our model, but getting the student to say he cared that the car got messed up afterwards was, you know, was the key there."* Owen's questioning and discussion is aligned with RO instructional strategies: the substance of the student's idea guides his instruction, and in engaging with this substance, Owen foregrounds disciplinary values and considerations over and above the incorrectness of the students' thinking.

These instructor statements mirror the literature's description of resources as being derived from legitimate experience or prior learning and appropriate in certain contexts but not all [5,9,14]. For example, the idea that 'closer means stronger' [8] is appropriate for thinking about why it's hotter closer to a fire, but it is not appropriate for explaining why the weather is warmer during the summer [5]. These instructors recognize the sensibility of their students' ideas and seek to make connections to situations where these ideas are appropriate and useful.

This theme came up less commonly in our interviews compared to the A and B, particularly in instances of sustained conversation like with John and Owen.

IV. DISSUSION AND CONCLUSIONS

In this paper, we present three specific ways post-secondary physics instructors take up RO framings in conversations about their instructional strategies, goals, and materials. Our aim in presenting these three themes is to make visible the ideas and motivations faculty may already have that are aligned with resources theory which can inform the creation and dissemination of RO instructional materials.

In particular, our results suggest a dissemination strategy that is aligned with an asset-based agentic paradigm [4] where the goal is to emphasize how RO instructional materials support instructors in doing more of what they're already doing. For example, emphasizing how RO materials elicit novel student ideas and give opportunities for instructors to engage with those ideas may be exciting to instructors like Nadia and Keith. Paul's, John's, and Quinn's examples of building on students' prior knowledge suggest that materials that build on productive resources could support instructors like them in doing more of what they already do to encourage their students' learning. Similarly, Owen's and John's statements—which emphasize adapting problems to include contexts in which their students' ideas were aligned with the canon—may make (i) flexible materials with (ii) generative questions especially appealing. Framing the development and dissemination of instructional materials in this way is consistent with Remillard's conceptualization [26] of curriculum use as participation with the text, where classroom instruction is "influenced by both teacher and curriculum" and the two are in a "participatory relationship." This contrasts with a conceptualization of curriculum use as following or subverting the text, where the instructor is framed as an "enactor of planned curriculum."

Our results may also help RO curriculum developers construct dissemination materials, such as video cases, that cue the three framings we identified. For example, they could select video cases that showcase students' novel ideas, intuitions that are continuous with the canon, or correct ideas used in incorrect contexts, and include discussion questions that direct instructors' attention to these things. This may not only support adaptation but also RO implementation.

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