Editors' Suggestion

# Postsecondary physics curricula and Universal Design for Learning: Planning for diverse learners

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Federal legislation specifies equitable access to education for all students at all levels of education, including postsecondary. To explore how well the physics education research (PER) community is currently serving students who inherently vary in needs, abilities, and interests, four research-based curricula (Tutorials in Introductory Physics, Open Source Tutorials in Physics Sensemaking, Physics by Inquiry, and Next Generation Physical Science and Everyday Thinking) were compared with the Universal Design for Learning (UDL) framework. This framework originates in the education literature base and is composed of 3 guiding principles (1. Provide multiple means of representation, 2. provide multiple means of action and expression, and 3. provide multiple means for engagement) further described by 9 principles and 31 checkpoints. The UDL guidelines provide a framework for designing courses to be supportive of and accessible to all learners, taking into account variations among learners during curriculum development. Activities in these four curricula were analyzed for alignment between the in-class curricular elements and the UDL guidelines. Overall, all of the curricula aligned with two of the checkpoints: foster collaboration and community and support planning and strategy development. However, the curricula were unaligned with many of the checkpoints, specifically with regards to providing multiple means of engagement. Who we are prepared to teach indicates who we expect to participate in the physics community. We propose suggestions for modifications to existing curricula and for future curricula to better support all learners. We also argue that, if these research-based curricula do not meet federal legislative guidelines about accessibility for all students, the burden of creating an accessible environment and complying with these federal laws falls on the instructors, which could deter them from using the curricula. If we as a community want instructors to use high quality, research-based curricula, curriculum developers should prioritize supporting all learners.

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## I. INTRODUCTION

Students with disabilities make up over 10% of the undergraduate student population in the United States [1]. Of the students with disabilities in postsecondary education, 25% enroll in science and engineering fields [2]. Federal law requires postsecondary institutions to provide equal access to students with disabilities. However, multiple universities in the United States have been faced with litigation for failing to provide such access. For example, two students with assistance from the National Federation for the Blind brought suit against Florida State University for failing to provide reasonable accommodations and accessible technology; specifically, the students stated they did not have equal access to the software used for homework and exams or the clicker response systems used in their mathematics class [3]. Harvard University and the Massachusetts Institute of Technology were sued by the National Association of the Deaf in response to online lectures, courses, and other educational materials that did not have adequate captions [4].

Since one goal of the physics education research (PER) community is to develop curricula and technology that support student learning, and to have those materials adopted by instructors across the country and world, issues of access for all students should be *a priority* in the development process. Not only do inaccessible curricula and technology put instructors and institutions at risk of violating federal laws, they also send the message that we do not anticipate certain students will engage in learning physics. While there have been studies focusing on how to support students with disabilities in physics (for example,

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see Refs. [5–8]), a corpus analysis of Physical Review Physics Education Research found that fewer than 1% of articles referred to any form of disability, which indicates that there may not have historically been much attention given to equitable access in our curriculum development [9].

Universal Design for Learning (UDL) provides a framework to plan for providing access to students with diverse needs, abilities, and interests [10]. A common misconception is that "UDL is just good teaching" [11]. As such, one might expect that well-designed, research-based curricula would naturally align with the UDL framework. In order to test this, we selected four high-quality physics curricula to explore the extent to which their curricular materials align with the UDL framework. Physics curriculum developers focus on supporting student learning, putting into practice values of the broader physics education community. With this analysis we identify examples of alignment between the physics curricula and the UDL framework, indicating presently shared values, and point out ideas that the physics education community can adapt from UDL to better support all students.

### A. Students with disabilities in postsecondary education

Students with disabilities are enrolling in postsecondary schools with increasing numbers [12]. A Government Accountability Office report found that "the number of students with disabilities pursuing postsecondary education is growing and this will further challenge current thinking about how to support them and schools' capacity to effectively meet their educational needs" [1] (p. 32). Students with disabilities made up nearly 11% of students pursuing postsecondary degrees in 2008, and the population appears to have grown [1]. However, the exact proportion of postsecondary students with disabilities is unknown because only students enrolled with an institution's disabilities or accessibility office can be quantified, and not all students choose to disclose their disability to the university [13].

The distribution of disability types has also been changing. For example, in 2000 only 7% of students with disabilities reported having attention-deficit hyperactivity disorder (ADHD); in 2008 this had increased to 19%. Students with autism spectrum disorders, psychological disabilities, and chronic medical conditions, as well as veterans with newly acquired disabilities, are additional groups with increasing presence in higher education [1]. Many of these disabilities are "invisible," so an instructor may not know they have a student with a disability in their course, especially if that student has chosen not to disclose [14].

While the number of students with disabilities in postsecondary education has been increasing, students with disabilities are still under-represented in science, technology, engineering, and mathematics (STEM) degree programs. Students with disabilities make up about 13.7% of the school aged population, but only 10% of United States workforce and 5% of STEM workforce are composed of people with disabilities [15].

Many students with disabilities are capable of completing STEM degrees and achieving STEM careers. Economic projections suggest an increasing need to recruit more STEM majors [16]. People with disabilities of working age are employed at less than half the rate of people without disabilities, and the median earnings of people with disabilities are about two-thirds the median earnings of people without disabilities [17]. While still present, the disparity is smaller in STEM fields, with 64.8% of scientists and engineers with a disability finding employment compared to 83.2% of those without a disability[1] [2]. Thus, it is important to improve the learning environment for students with disabilities in the postsecondary setting to increase retention of students with disabilities in STEM. Independent of the number of students with disabilities in STEM, inclusive classroom practices should be investigated and implemented.

### B. Faculty preparation to support students with disabilities

While the proportion of students with disabilities in the postsecondary setting is on the rise, faculty lack the knowledge and skills necessary to support these students. Less than 11% of university science faculty reported feeling adequately prepared to teach students with disabilities [18]. Also, a Government Accountability Office report found that not all faculty are aware of the legal requirements regarding supporting students with disabilities nor have experience in offering such support [1]. Rao and Gartin found that STEM faculty at a south-central land grant university were less willing than their non-STEM colleagues to provide academic accommodations to students with disabilities [19,20]. Thus, curricula should be developed to support faculty in providing equal access to all students, rather than expecting faculty to adapt the curriculum to provide such access.

### C. Disability laws in postsecondary education

There are two main laws supporting students with disabilities in the postsecondary education setting. Section 504 of the Rehabilitation Act of 1973 (Public Law 93–112) prohibits discrimination on the basis of disabling conditions by programs and activities receiving or benefitting from federal financial assistance, protection

[1]People with full-time and part-time employment were included in the employed category and those who are seeking employment, not seeking employment, and retired were included in the not employed category.

that was extended to all citizens with disabilities through the American with Disabilities Act of 1990 (public law 100–336) [21,22]. Subpart E of the rules and regulations for Sec. 504 addresses postsecondary educational services and specifically prohibits discrimination in the areas of recruitment and admissions, academic and athletic programs and activities, student examinations and evaluations, housing, financial aid, counseling, and career planning and placement [23]. In addition, schools are required to make modifications to academic requirements and other rules that discriminate against students with disabilities, to provide auxiliary aids such as taped texts and readers to students with disabilities, and to ensure social organizations supported by the school do not discriminate on the basis of disability.

Section 508 is federal legislation that requires "federal agencies to make their electronic and information technology (EIT) accessible to people with disabilities." [24]. Section 508 provides specific guidelines for minimum steps that must be taken to ensure a website is accessible to people with disabilities. Note that Sec. 508 does not apply to the private sector, which includes private online postsecondary schools. However, many schools voluntarily comply with Sec. 508 so that electronic course materials, online classrooms, and curricula are compatible with assistive technology and fully accessible to all students. Some of the tools that are used in this endeavor are the captioning of videos and ensuring that screen readers work with written materials [25].

### D. UDL framework and guidelines

One possible method for supporting individuals with disabilities is to apply the UDL framework to instructional material design and implementation, thereby proactively

TABLE I. Universal Design for Learning (UDL) guidelines [10].

| Principle | Guideline | Checkpoint | Description |
|---|---|---|---|
| Provide multiple means of representation | 1. Provide options for perception | 1.1 | Offer ways of customizing the display of information |
| | | 1.2 | Offer alternatives for auditory information |
| | | 1.3 | Offer alternatives for visual information |
| | 2. Provide options for language, mathematical expressions, and symbols | 2.1 | Clarify vocabulary and symbols |
| | | 2.2 | Clarify syntax and structure |
| | | 2.3 | Support decoding of text, mathematical notation, and symbols |
| | | 2.4 | Promote understanding across languages |
| | | 2.5 | Illustrate through multiple media |
| | 3. Provide options for comprehension | 3.1 | Activate or supply background knowledge |
| | | 3.2 | Highlight patterns, critical features, big ideas, and relationships |
| | | 3.3 | Guide information processing, visualization, and manipulation |
| | | 3.4 | Maximize transfer and generalization |
| Provide multiple means of action and expression | 4. Provide options for physical action | 4.1 | Vary the methods for response and navigation |
| | | 4.2 | Optimize access to tools and assistive technologies |
| | 5. Provide options for expression and communication | 5.1 | Use multiple media for communication |
| | | 5.2 | Use multiple tools for construction and composition |
| | | 5.3 | Build fluencies with graduated levels of support for practice and performance |
| | 6. Provide options for executive functions | 6.1 | Guide appropriate goal-setting |
| | | 6.2 | Support planning and strategy development |
| | | 6.3 | Facilitate managing information and resources |
| | | 6.4 | Enhance capacity for monitoring progress |
| Provide multiple means of engagement | 7. Provide options for recruiting interest | 7.1 | Optimize individual choice and autonomy |
| | | 7.2 | Optimize relevance, value, and authenticity |
| | | 7.3 | Minimize threats and distractions |
| | 8. Provide options for sustaining effort and persistence | 8.1 | Heighten salience of goals and objectives |
| | | 8.2 | Vary demands and resources to optimize challenge |
| | | 8.3 | Foster collaboration and community |
| | | 8.4 | Increase mastery-oriented feedback |
| | 9. Provide options for self-regulation | 9.1 | Promote expectations and beliefs that optimize motivation |
| | | 9.2 | Facilitate personal coping skills and strategies |
| | | 9.3 | Develop self-assessment and reflection |

circumventing curriculum barriers [26]. This is accomplished through careful consideration of the broad range of needs, motivations, and strengths across all learners, including traditionally marginalized populations such as English language learners, those with disabilities, and students with diverse cultural backgrounds as well as the "top" or "model" students [27]. Using UDL, instruction is framed around three guiding principles: (a) multiple means of representation (i.e., providing content through multiple methods), (b) multiple means of action and expression (i.e., providing opportunities for students to demonstrate their understanding in multiple ways), and (c) multiple means of engagement (i.e., considering how to engage students through a variety of pathways) [10]. Each principle is further delineated by guidelines and finer-grained checkpoints in Table I.

### E. Physics education research curriculum development

A recent resource letter by Meltzer and Thornton summarized the state of research-based active-learning instruction in the postsecondary physics community [28]. Meltzer and Thornton identified three criteria that all research-based active-learning instructional methods shared: "(1) they are explicitly based on research in the learning and teaching of physics; (2) they incorporate classroom and/or laboratory activities that require all students to express their thinking through speaking, writing, or other actions that go beyond listening and the copying of notes, or execution of prescribed procedures; (3) they have been tested repeatedly in actual classroom settings and have yielded objective evidence of improved student learning." [28] (p. 478). While these features are shared by all of the methods, Meltzer and Thornton explain that they do not provide an adequate description of the commonalities across these methods. They identified an additional 13 characteristics that are present to varying extents across active-learning instructional methods in physics, listed in Table II.

TABLE II. Meltzer and Thornton's characteristics shared by most research-based active-learning instructional methods in physics.

| |
|---|
| (a) Instruction is informed and explicitly guided by research regarding students pre-instruction knowledge state and learning trajectory. |
| (b) Specific student ideas are elicited and addressed. |
| (c) Students are encouraged to "figure things out for themselves." |
| (d) Students engage in a variety of problem-solving activities during class time. |
| (e) Students express their reasoning explicitly. |
| (f) Students often work together in small groups. |
| (g) Students receive rapid feedback in the course of their investigative or problem-solving activity. |
| (h) Qualitative reasoning and conceptual thinking are emphasized. |
| (i) Problems are posed in a wide variety of contexts and representations. |
| (j) Instruction frequently incorporates use of actual physical systems in problem solving. |
| (k) Instruction recognizes the need to reflect on one's own problem-solving practice. |
| (l) Instruction emphasizes linking of concepts into well-organized hierarchical structures. |
| (m) Instruction integrates both appropriate content (based on knowledge of students' thinking) and appropriate behaviors (requiring active student engagement). |

We interpret the list of characteristics in Table II to represent many of the shared values of curriculum developers in the PER community. Since both the special education community and the PER community are engaged in improving student learning, there is potential for some overlap between these values and the UDL guidelines. However, given the two communities' unique foci, it is also likely the PER community has not focused on all of the strategies described in the UDL framework.

### F. Purpose

The purpose of this study was to determine the alignment between established, reformed physics curricula and the Universal Design for Learning framework [29]. We note that this analysis does not align with the aspects of student learning the curriculum developers specifically targeted and does not speak to the overall quality of the curricula. As teachers, we have chosen to use these curricula in our own classes. However, this analysis helps the community understand how current curricula support learners at all ends of the ability spectrum and how the curricula may be modified or redesigned to better address all students' needs. Specifically, we investigated

(1) How do reformed physics curricula support diverse learners as measured by their alignment with the Universal Design for Learning guidelines?
(2) How can physics curricula be modified to better support all physics students (and thereby better align with the Universal Design for Learning guidelines)?

## II. METHODOLOGY

We selected four established, commonly employed, reformed curricula for analysis; all were included in Meltzer and Thornton's resource letter on active-learning instruction in physics [28]. In this section we describe the curriculum sampling, the selected curricula, the analytic techniques employed, and the investigation of the validity and reliability of the data analysis.

### A. Curriculum selection

The physics curricula analyzed in this paper were selected because they were reformed, established, and commonly employed by the physics community. We chose reformed, active-learning curricula because such curricula tend to be more student focused (as opposed to instructor focused) and therefore more likely align with the UDL guidelines. Reformed curricula were also selected because there are numerous studies showing these curricula are more effective than traditional, lecture-based curricula (for example, Refs. [30–32]) and therefore offer a method to improve student learning, a major goal of the PER community. Previous research has indicated that active-learning classes also can have unintended impacts on specific populations of students. For example, Cooper and Brownell found that students who identified as part of the lesbian, gay, bisexual, transgender, queer, intersex, and asexual (LGBTQIA) community experienced challenges and benefits from active learning that were different from their peers [33]. These unintended impacts may also disproportionally affect students with disabilities in active learning classes and thus, these types of curricula were included in our sample.

The curricula selected met the three research-based, active-learning criteria proposed by Meltzer and Thorntorn (see Sec. I. E) [28]. The curricula were commonly employed by practitioners both in and out of the PER community and were chosen to span the range of introductory physics courses (e.g., calculus-based, conceptual). Only the in-class portion of the curricula and instructor guides were analyzed so as to maintain consistency across curricula. This means that assignments for students to complete outside of class and other out of class curricular components were not included. Four curricula were chosen for analysis in this study: the Open Source Tutorials in Physics Sensemaking (OST) [34], Physics by Inquiry (PbI) [35], Next Generation Physical Science and Everyday Thinking (Next Gen PET) [36], and Tutorials in Introductory Physics (Tutorials) [37]. Below is a brief description of each curriculum.

### *1. Tutorials in Introductory Physics*

The Tutorials in Introductory Physics (Tutorials) were developed by the University of Washington PER group [37] as a supplement to introductory calculus-based or algebra-based physics courses. The Tutorials have an emphasis on "the development of important physical concepts and scientific reasoning skills, not on solving the standard quantitative problems found in traditional textbooks" (p. iii). The Tutorials are a set of 50 guided activities that are intended to help students engage with the physics content in a meaningful way. Numerous studies into the implementation and effect of implementation in introductory physics courses have been conducted. Overall, when compared with a traditional curriculum, courses in which the Tutorials were implemented showed higher conceptual learning gains (as measured by the Force Concept Inventory [38] and the Force and Motion Concept Evaluation [39]), higher understanding of physics concepts covered in the tutorials [39], higher midterm exam scores [38], and more expertlike attitudes and beliefs about physics (as measured by the Colorado Learning Attitudes about Science Survey [39]).

### *2. Open Source Tutorials in Physics Sensemaking*

The Open Source Tutorials in Physics Sensemaking (OST) curriculum was developed by Scherr *et al.* as an open-source version of other widely used, published reformed curricula (e.g., Tutorials) [34]. The tutorials focus on building students' physical intuition, strengthening students' understanding of scientific reasoning, and establishing connections between physics and everyday life [28]. In addition to an emphasis on conceptual development, the OSTs also focus on "helping students become more reflective about their learning and more sophisticated in their 'epistemologies'—their views about what it means to learn and understand physics." [40]. The OSTs are composed of a set of two suites of open-source tutorials and interactive learning demonstrations (ILD), both of which were analyzed in this study. The tutorials are designed to be done in small groups at small tables while the ILDs are designed to be done in an algebra-based lecture setting by small groups of students. There are 13 tutorials and 8 ILDs across the suites, most of which are accompanied by instructor guides. One advantage of this curriculum is that the tutorials, ILDs, and instructor guides are provided free of charge and in a digital format, which allows for easy customization. Research has demonstrated that students who used the OSTs, when compared with other reformed, tutorial based curricula, had superior performance on exams and greater conceptual learning gains (as measured by the Force and Motion Concept Evaluation) [41].

### *3. Physics by Inquiry*

The Physics by Inquiry (PbI) curriculum was developed by the University of Washington PER group [35] for use in physics courses for preservice and in-service teachers. The curriculum is broken down into two books with a total of 107 laboratory-based modules. The authors state "the modules have been explicitly designed to develop scientific reasoning skills and to provide practice in relating scientific concepts, representations, and models to real world phenomena" (p. iii). The modules have an emphasis on exploration and the practices of science as a means for learning physics concepts and are intended to be completed in small groups in a laboratory setting.

Because the PbI curriculum is so widely disseminated and used, there are numerous studies investigating its effectiveness and implementation in classroom settings (for example, Ref. [42]). Students in courses in which the PbI curriculum was used performed significantly better on both qualitative and quantitative physics problems [43]. Students' attitudes and beliefs about physics were also measured across multiple implementations at multiple institutions. Typically, traditional courses yield shifts towards more novicelike attitudes and beliefs unless the course specifically addresses students' epistemologies. But when the PbI curriculum was used, overall student attitudes and beliefs shifted toward more expertlike over the course of a semester [44].

#### 4. Next Generation Physical Science and Everyday Thinking

The Next Generation Physical Science and Everyday Thinking (Next Gen PET) [36] curriculum was developed by a large collaboration as a follow up to the Physics and Everyday Thinking [45] curriculum. It was developed for use in a class for preservice elementary school teachers. The authors state that students "make explicit connections between their own learning; the learning and teaching of children in elementary school; and the core ideas, science and engineering practices, and crosscutting concepts of the NGSS [Next Generation Science Standards]." The focus of the curriculum is on conceptual understanding as well as the process and logic of science instead of mathematical formalism or memorization. The curriculum has two versions: one intended for use in a lecture setting and the other for use in a studio-physics style classroom. For this paper we analyzed the studio-physics curriculum because it is more commonly used. The studio version of the Next Gen PET is composed of a series of 41 activities that include discussions and experiments that students are asked to perform in groups. The Next Gen PET curriculum is stand alone and covers most aspects of a physics courses. Each activity has an instructor guide with a pedagogical goal and materials list along with an answer key with sample student responses.

### B. Data analysis

In order to determine if the selected physics curricula are aligned with the UDL guidelines, a qualitative analysis of each curriculum was conducted. The unit of analysis for this study was an individual activity in the curricula (called tutorials in the OSTs and the Tutorials, modules in PbI, and activities in Next Gen PET). Each written activity in the curricula was investigated to determine if it aligned with each of the UDL checkpoints except the two units from Next Gen PET that focused on chemistry topics (Unit Physical Change and Unit Chemical Reactions).

The UDL checkpoint operationalizations implemented in this study came from the UDL Guidelines Full-Text Representation [10]. The operationalizations included an overall description of the concepts behind UDL, along with detailed descriptions of each principle, guideline, and checkpoint. The description for each checkpoint included a definition and examples of how the checkpoint could be implemented in a classroom. We used these detailed descriptions, definitions, and implementation examples as the basis for our UDL coding scheme. The UDL guidelines provide a new lens through which to examine these physics curricula. Some of the checkpoints represent values not frequently highlighted in the PER community. For example, checkpoint 1.3 (offer alternatives for visual information) emphasizes the needs of students with visual impairments or difficulty processing visual information. Other checkpoints use terms that are familiar to the PER community, but in a disciplinary specific way. For example, checkpoint 3.4 (maximize generalization and transfer) is operationalized, in terms of providing checklists or organizers, providing graphic organizers or concept maps, or embedding new ideas into familiar contexts. Because our purpose is to identify strategies from the UDL framework that the PER community could adopt, we emphasize the definitions and operationalizations from the UDL framework in these cases of disciplinary tension. See the Supplemental Material at for operationalizations of each UDL checkpoint [46].

ssroom is run that would not appear in a written text. For example, we would not expect UDL checkpoint 7.3 (minimize threats and distractions) to appear in the written activities for students because its focus is on classroom culture rather than the tasks the students are asked to complete. We made no assumptions about how the curricula were implemented in a classroom setting unless the curricular materials (e.g., instructor guides) specifically described aspects of how it should be implemented. Thus, the curricula examined may have greater alignment with the UDL checkpoints than indicated in this analysis due to the specifics of how the curricula are implemented in the classroom.

Similarly, typically curricula are not used as is in classrooms; instructors make adjustments to the curricula to fit the needs of the setting in which they are teaching and the needs of their students. Adjustments made by individual instructors to accommodate individual student needs were not captured in this analysis. Therefore, the selected physics curricula could be implemented in such a way as to align more closely with the UDL guidelines than found in this study.

The UDL operationalizations were applied to each activity in each of the four curricula to investigate the alignment between the curricula and the UDL guidelines. To ensure fidelity of implementation, the analysis was conducted one checkpoint at a time; all activities in a specific curriculum were investigated for alignment with a certain checkpoint, and the process was completed iteratively until each checkpoint had been analyzed. This process was completed by the primary coder (ES).

The curricula included in this study were not designed to explicitly align with the UDL guidelines. Thus, during the alignment process we counted as aligned all activities that met any portion of the UDL checkpoint description at least once. If the curricula were designed to align with UDL, we would expect there to be richer alignment (e.g., aligning with more than one component or having multiple parts of the activity that aligned).

### C. Reliability

The reliability of the data analysis was investigated to ensure our results reflect the actual alignment between the curricula and the UDL guidelines.

To investigate the reliability of the primary analyst's coding, an inter-rater reliability process was conducted. Two secondary coders were selected to separately code a portion of the activities. Both secondary coders are graduate students; one is pursing a doctoral degree in education and the other in physics, with research on physics education. Both secondary coders had employed and worked with the UDL guidelines prior to the start of the study. The primary coder was a postdoctoral researcher whose expertise lies in qualitative research in physics education. The coders were selected to enhance the validity of the study by including both physics and UDL experts in the data analysis process.

In the first step of the training process, the primary coder walked both secondary coders through an entire activity, describing how it was aligned or unaligned with each UDL checkpoint. Next, the three coders analyzed a common activity individually and then discussed their alignments and came to agreement. This training process was conducted on activities from the Tutorials curriculum.

The primary coder then analyzed all of the activities for a particular curriculum, and the secondary coders each analyzed at least 9% of the total activities in each. Specifically, each secondary coder analyzed a separate 17% for the OSTs, 9% for PbI, 20% for the Next Gen PET, and 16% for the Tutorials. With each coders' analysis combined, at least 18% of all activities were coded by two coders. After the individual coding phase, the three coders met to discuss their analysis.

The discussion process was completed one curriculum at a time and the co-coded activities were discussed one UDL checkpoint at a time. When disagreements arose, the reasoning behind the raters' unalignment or alignment were discussed as related to the UDL implementation guide and examples. Typically the disagreements were resolved by refining operationalizations of the UDL checkpoint due to unique features of each curriculum. For example, the Next Gen PET curriculum was distinct in that it provided explicit prompts for each step in a sequential process (checkpoint 3.3). Thus, before discussion the primary and secondary raters disagreed as this specific component of the operationalization of checkpoint 3.3 had not been identified previously. After a brief discussion, complete agreement was reached (see the Supplemental Material 2 [46] for a deeper discussion of the disagreements and resolutions).

TABLE III. Inter-rater reliability results. Bold font indicates at least substantial agreement between the raters.

| | Before discussion | | After discussion | |
|---|---|---|---|---|
| UDL principle | Education rater | Physics rater | Education rater | Physics rater |
| 1 | **0.70** | **0.84** | **0.93** | **0.98** |
| 2 | **0.65** | **0.70** | **0.95** | **0.95** |
| 3 | 0.51 | 0.39 | **0.98** | **0.88** |
| 4 | **1.00** | **0.90** | **1.00** | **1.00** |
| 5 | 0.44 | 0.39 | **0.92** | **0.98** |
| 6 | **0.78** | 0.47 | **0.95** | **0.97** |
| 7 | **0.95** | **0.78** | **1.00** | **0.89** |
| 8 | **0.84** | 0.47 | **1.00** | **0.92** |
| 9 | **0.96** | **1.00** | **1.00** | **1.00** |

If the checkpoint operationalization refinement affected the previously completed analysis, the refinements were applied to all previously analyzed activities. After discussion, most instances were agreed upon by all three raters. The primary rater's responses were included in the analysis for the few instances where disagreement persisted after discussion.

We used Gwet's AC1 to investigate the degree of agreement between raters. Gwet's AC1 is a statistic that measures inter-rater consistency, (e.g., the agreement between raters). It is similar to Cohen's kappa in interpretation but is more robust for data sets that have low trait prevalence [47]. Gwet's AC1 for each principle for each secondary rater (e.g., education graduate student and physics graduate student) before and after the discussion is listed in Table III. Gwet's AC1 ranges from 0 (meaning no agreement) to 1 (meaning perfect agreement). AC1 values between 0.61 and 0.8 indicate substantial agreement and values greater than 0.80 indicate almost perfect agreement [48]. Bold font indicates at minimum substantial agreement between raters. All of the after discussion Gwet's AC1s were greater than 0.80 and therefore support the reliability of the data analysis.

## III. FINDINGS

Table IV displays the percent of activities within each curriculum that were aligned with each checkpoint. (Recall that an activity was considered aligned if it aligned with at least one component of a checkpoint at least once.) We consider a curriculum to be aligned with a checkpoint if at least 75% of the activities were aligned with that checkpoint, as indicated by an asterisk in Table IV. The threshold of 75% was chosen in order to characterize

TABLE IV. Physics curricula and UDL alignment (percent alignment) and overall alignment.

| Description | UDL Checkpoint | OST | PbI | Next Gen PET | Tutorials | Overall[a] |
|---|---|---|---|---|---|---|
| Offer ways of customizing the display of information | 1.1 | 100* | 0 | 100* | 0 | M |
| Offer alternatives for auditory information | 1.2 | 0 | 0 | 0 | 0 | U-NA |
| Offer alternatives for visual information | 1.3 | 86.7* | 70.1 | 51.0 | 96.0* | M |
| Clarify vocabulary and symbols | 2.1 | 54.5 | 78.5* | 83.7* | 78.0* | MA |
| Clarify syntax and structure | 2.2 | 4.6 | 3.7 | 22.4 | 2.0 | U |
| Support decoding of text, mathematical notation, and symbols | 2.3 | 0 | 0 | 0 | 0 | U |
| Promote understanding across languages | 2.4 | 0 | 0 | 0 | 0 | U |
| Illustrate through multiple media | 2.5 | 59.1 | 64.5 | 100* | 96.0* | M |
| Activate or supply background knowledge | 3.1 | 36.4 | 51.4 | 75.5* | 6.0 | MU |
| Highlight patterns, critical features, big ideas, and relationships | 3.2 | 40.9 | 86.0* | 100* | 98.0* | MA |
| Guide information processing, visualization, and manipulation | 3.3 | 0 | 0 | 100* | 0 | MU |
| Maximize transfer and generalization | 3.4 | 0 | 0 | 55.1 | 4.0 | U |
| Vary the methods for response and navigation | 4.1 | 0 | 0 | 0 | 0 | U-IV |
| Optimize access to tools and assistive technologies | 4.2 | 0 | 0 | 0 | 0 | U-IV |
| Use multiple media for communication | 5.1 | 40.9 | 35.5 | 77.6* | 80.0* | M |
| Use multiple tools for construction and composition | 5.2 | 0 | 0 | 0 | 0 | U-IV |
| Build fluencies with graduated levels of support for practice and performance | 5.3 | 100* | 76.6* | 16.3 | 0 | M-IV |
| Guide appropriate goal-setting | 6.1 | 0 | 0 | 0 | 0 | U |
| Support planning and strategy development | 6.2 | 90.9* | 100* | 91.8* | 98.0* | A |
| Facilitate managing information and resources | 6.3 | 0 | 72.0 | 67.3 | 2.0 | U |
| Enhance capacity for monitoring progress | 6.4 | 45.5 | 0 | 0 | 2.0 | U-IV |
| Optimize individual choice and autonomy | 7.1 | 0 | 0 | 16.3 | 0 | U |
| Optimize relevance, value, and authenticity | 7.2 | 36.4 | 0 | 32.7 | 0 | U |
| Minimize threats and distractions | 7.3 | 0 | 0 | 0 | 0 | U-IV |
| Heighten salience of goals and objectives | 8.1 | 4.6 | 0 | 93.9* | 0 | MU |
| Vary demands and resources to optimize challenge | 8.2 | 4.6 | 0 | 12.2 | 0 | U |
| Foster collaboration and community | 8.3 | 100* | 100* | 100* | 100* | A |
| Increase mastery-oriented feedback | 8.4 | 100* | 0 | 0 | 0 | MA-IV |
| Promote expectations and beliefs that optimize motivation | 9.1 | 0 | 0 | 0 | 0 | U |
| Facilitate personal coping skills and strategies | 9.2 | 0 | 0 | 0 | 0 | U-IV |
| Develop self-assessment and reflection | 9.3 | 27.3 | 0 | 0 | 0 | U |

*Indicates alignment (at least 75% of activities aligned) between UDL checkpoint and specific physics curriculum.
[a]In the overall alignment column, U represents unaligned (none of the curricula aligned), MU represents mostly unaligned (1 curriculum aligned), M represents mixed alignment (2 curricula aligned), MA represents mostly aligned (3 curricula aligned), and A represents aligned (all 4 curricula aligned). The letters represent the source of the unalignments (IV represents unalignment due to implementation variability and NA represents unalignment due to nonapplicability).

the overall alignment between the selected curricula and the UDL guidelines.

Overall, there is not much alignment between the physics curricula and the UDL guidelines. This is not unexpected because the physics curricula were not likely designed with the UDL guidelines in mind.

The last column in Table IV shows the alignment of the four curricula overall with the UDL guidelines, where U represents unaligned (0 out of 4 curricula aligned), MU represents mostly unaligned (1 out of 4 curricula aligned), M represents mixed alignment (2 out of 4 curricula aligned), MA represents mostly aligned (3 out of 4 curricula aligned), and A represents aligned (all 4 curricula aligned). The overall alignment between the four curricula and each of the UDL checkpoints is also shown in Fig. 1.

### A. Sources of unalignment

Through our analysis we identified three distinct types of unalignment between the curricula and the UDL guidelines: (i) unalignment that occurred because components of the curriculum did not best serve all students; (ii) unalignment due to implementation variability, or variation in how instructors could implement the curriculum; and (iii) unalignment due to checkpoints that were not applicable to the particular curricular component. The type of unalignment is indicated in the last column of Table IV, where U-IV represents unaligned due to implementation variability and U-NA represents unaligned due to the checkpoint being not applicable in the curriculum.

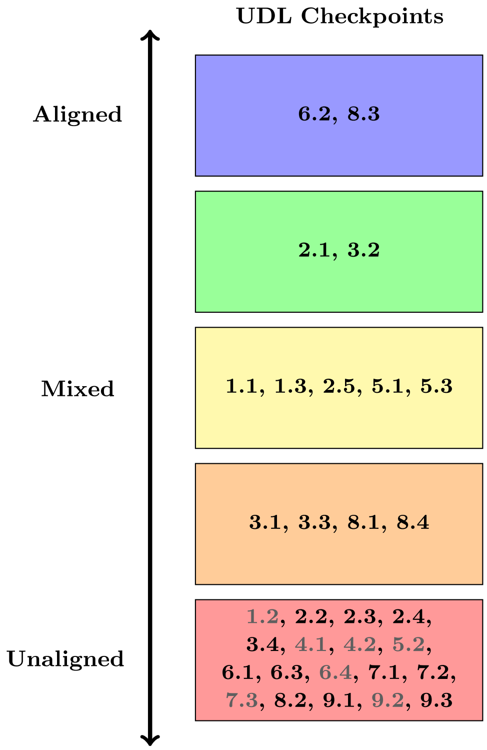


FIG. 1. Ranking of the alignment between the UDL checkpoints and the four selected physics curricula overall. Gray shading indicates unalignments due to implementation variability and nonapplicability.

The first source of unalignment is perhaps the most obvious: the curricula has room for improvement in order to best serve all students. For example, all four of the selected curricula do not promote understanding across languages (checkpoint 2.4). Therefore, if students have difficulties with the dominant language, they will have challenges in understanding the course material.

The second source of unalignment came from the fact that only the printed curricular materials were analyzed. Since we did not have access to the classrooms in which the curricula were implemented, we could not determine how the curricula are used in the classroom which gave rise to some unalignment. For example, checkpoint 7.3 (minimize threats and distractions) would manifest itself in the classroom environment or the instructor guide. We cannot see if the instructor has created a safe space for all students without being in the classroom or having it explicated in the instructor guide.

The final source of unalignment is due to specifics of the curricula making a checkpoint not applicable. For example, none of the four selected curricula had auditory components. Therefore, checkpoint 1.2 (offer alternatives for auditory information) is not applicable because no auditory components to provide alternatives for were present in the curricula.

### B. Disciplinary differences in word meaning

One interesting facet of the analysis was that there was a disciplinary component to the meaning and usages of some words that were used by both curriculum developers in physics education and the UDL guidelines, but with different meanings. One example is the word "experiment." The term experiment when used in a physics classroom context usually conjures thoughts of conducting an experiment or demonstration. Often, the questions to investigate, equipment, and procedures are supplied to the students by the instructor. On the other hand, the UDL guidelines use the term experiment to express open exploration into a phenomenon. These two definitions of experiment would manifest themselves in very different ways in the classroom.

A similar disciplinary difference occurs in checkpoint 3.1 (activate or supply background knowledge), in which activate and supply are operationalized differently than is typical in the PER community. Activating or supplying background knowledge in checkpoint 3.1 is operationalized as, for example, providing advanced organizers (e.g., concept maps), bridging concepts with analogies and metaphors, and making cross-disciplinary connections (e.g., teaching writing skills in science courses). These definitions are quite different than how the PER community typically defines activating and supplying background knowledge.

For the purposes of our study, we used the UDL guideline definitions of words as we sought to see how well the curricula were aligned with these guidelines. This leads to some surprising results, e.g., low alignment with checkpoints 2.1, 2.2, 3.1, 3.4, and 8.4. Curriculum developers should be aware of these differences in meaning as they work with the UDL guidelines. Different perspectives and backgrounds yield different definitions.

## IV. DISCUSSION

Below is a discussion of the alignment and unalignment between the UDL guidelines and the four selected physics curricula. We discuss areas where the physics curricula are currently well serving the needs, abilities, and interests of diverse students along with areas of suggested improvement. Only selected checkpoints are discussed here, but an example for each is provided in the Appendix.

### A. Alignment

#### *1. Supporting planning and strategy development*

Overall, checkpoint 6.2 was well aligned with all four curricula. This checkpoint was identified when the questions asked students to "Stop and think." or "Explain your reasoning." These prompts serve as a "speedbump" that slows students down during their problem solving to support their planning and strategy development, giving students the time and space to plan before implementation of an action. While all students benefit from support for planning and strategy development, students learning in a new domain and students with executive function disorders will particularly benefit. These types of prompts can be added at the end of questions that are typically difficult for students or problems that require a large cognitive load. Explicit problem solving frameworks (e.g., Wright and Williams [49] or Leonard *et al.* [50]) would also align with this checkpoint. It may not be surprising that checkpoint 6.2 is well represented in the selected curricula, as it aligns with the characteristic that "students express their reasoning explicitly" identified by Meltzer and Thornton as common to research-based active learning methods in physics education [28].

#### *2. Fostering collaboration and community*

Checkpoint 8.3 was also well represented in all four curricula. All four curricula tasked students with working in small groups as they worked through the activities. Because students were asked to work in groups, the curricula were fostering collaboration between students as well as building a community of learners in the physics classroom. Group work is common in many reformed physics curricula. [28,51] Group work skills are essential for most jobs in the 21$^{st}$ century and therefore students must be given opportunities to practice these skills in a supportive and carefully structured environment [29]. The UDL guidelines also state that the group work should be "structured" by, for example, stating clear expectations for group work and group roles. None of the four curricula meet this definition of structured. Students who are uncomfortable with navigating social interactions as well as those with disabilities that affect their abilities to interact with others (e.g., autism spectrum disorders) will be particularly affected by the lack of structure in group work. Thus, future curricula should clearly state expectations to help support all learners.

#### *3. Clarifying vocabulary and symbols*

PbI, Next Gen PET, and the Tutorials aligned well with checkpoint 2.1. This checkpoint was identified when words and/or symbols were defined in the text. For example, the excerpt below is found in the introduction to an activity in the Next Gen PET curriculum:

> *Some magnetized objects retain their magnetism for very long periods of time, and we call them permanent magnets (Unit M, p. 24) [36].*

In this example, the term "permanent magnets" is defined before it is used in the rest of the curriculum. Similarly, the Tutorials provide definitions of vocabulary and symbols throughout the text; for example,

> *Is the magnitude of the final momentum of cart A ($p_{Af}$) greater than, less than, or equal to the magnitude of the final momentum of cart B ($p_{Bf}$)? Explain. [37] (p. 44).*

In this excerpt, the symbol for momentum of each cart is clearly defined in the question. Although the Tutorials were designed as a supplement to a course, the new symbols and vocabulary were defined to support student understanding. Learners coming from different cultural and lexical backgrounds and with nondominant native languages can have particular difficulty accessing information when words and symbols are not clearly defined. To best support all learners, future curricula should include definitions of all requisite variables, symbols, and vocabulary. Links to the new vocabulary in nondominant language dictionaries can also help support students whose first language is not the dominant language (Checkpoint 4.2).

On the other hand, the OSTs did not align with this checkpoint because terms and symbols were not defined in the text for at least 75% of activities. For example, the excerpt below is from ILD 7:

> *A hockey puck is a rubber disk. On an ice-covered pond, a puck is spinning in place; it's not going anywhere.*
>
> (A) *Why might a smart student say the puck does not have kinetic energy?*
>
> (B) *Why might a smart student say the puck does have kinetic energy?*
>
> (C) *Which argument do you think is correct? Does the spinning puck have kinetic energy? Why is the other argument flawed?*
>
> *(ILD 7, p. 1) [34].*

In this example, understanding the term kinetic energy is required for answering the question. The problem targets students' understanding of the similarities and differences between translational and rotational kinetic energy. Thus, students must have an understanding of the definition of kinetic energy (i.e., energy of motion) in order to understand the nuanced differences targeted in the problem. Because the term kinetic energy was not defined in the activity, it is unaligned with checkpoint 2.1.

However, the OSTs are intended to be a supplement to a course where the relevant symbols and terms are likely defined. Because our analysis only examined specific written components of the curricula, we did not have access to the details of the other curricular components where the information may have been presented for the first time. Thus, the curriculum as implemented in a course may be more aligned with the checkpoints than our analysis indicated. We recommend including reminders to the instructor in written instructor guides to review relevant background information before starting an activity if relevant disciplinary definitions are needed and not provided in the student version of the written activity.

#### 4. Highlighting patterns, critical features, big ideas, and relationships

Checkpoint 3.2 was aligned with the PbI, Next Gen PET, and Tutorials curricula because they employed italics, bolding, and outlines to help emphasize key features. This formatting helps to facilitate students' understanding of what is important and what is extraneous information while working through an activity. The ability to distinguish between such information is one main difference between experts and novices [29]. Therefore, physics curricula should assist students by giving them cues about the important information so that they can both process the information and build the skills to identify the salient features in the future. This checkpoint is one way that curricula could demonstrate the characteristic identified by Melzter and Thornton that research-based active learning methods in physics education often emphasize "linking of concepts into well-organized hierarchical structures" [28] (p. 489). Another aspect to consider is the compatibility of these practices with assistive technologies such as text-to-speech and text-to-Braille software, alternative keyboards, and alternative joysticks. While there has been some work done on the accessibility of bolding and italicizing [52], future work should focus on determining the compatibility of the practices suggested here with assistive technologies.

### B. Unalignment

Overall, the four physics curricula and the UDL guidelines were not well aligned. This is most likely because the physics curricula were not designed to align with the UDL guidelines and is not a judgment of their quality along other dimensions of student learning. But because the UDL guidelines were developed as a way to help students at all ends of the ability spectrum, this also implies that the current physics curricula could be modified in order to better support all learners. Again, only selected checkpoints are discussed here, but additional examples are provided in the Appendix.

#### 1. Supporting the spectrum of students' executive function skills

Checkpoints 6.1 and 6.4 relate to accommodating the spectrum of students' executive function skills; executive function skills are a clustered set of higher order cognitive abilities, such as planning, problem resolution, and working memory, that support work toward a goal [53]. Executive function skills are necessary for self-regulation, goal setting, and task persistence. Neither checkpoint was aligned with any of the four selected physics curricula (although alignment with 6.4 was found in 45% of OST activities). This implies that the physics curricula do not well support the variation in executive function skills of students enrolled in physics courses. Instructors must be aware of students' cognitive differences and build tasks into curricula that assist all students. An example from the OSTs is a "mistake-catching lesson" where the following question is posed:

> *Are you 100% comfortable with your understanding of this scenario, or is there still something that needs to be reconciled? Explain. [34] (Tutorial 3, p. 1).*

This question prompts students to self-reflect and to think metacognitively.

In fact, checkpoints 6.1 and 6.4 seem to align with Meltzer and Thornton's characteristic that research-based active learning methods in physics education tend to emphasize "the need to reflect on one's own problem-solving practice," which specifically involves "enunciating specific goals and planning specific solution strategies in advance," "checking results frequently during the problem solving process," and "reviewing the entire process to reflect on how one's thinking evolved, and to assess the effectiveness of one's strategies" [28] (p. 489). Thus, investigating how other curricula have implemented these checkpoints may help the physics education community better reach our own goals.

#### 2. Activating or supplying background knowledge

Checkpoint 3.1 was only aligned at the 75% level for one of the four curricula, which is a surprising result, since one focus of the physics education research community is identifying the ideas about physics that students bring with them to the classroom, such as misconceptions and resources [54]. However, from a UDL standpoint this checkpoint is operationalized in terms of explicitly linking to and activating prior knowledge in order to support students with varying backgrounds and abilities to determine the relevance of acquired knowledge (see Supplemental Material 1 [46] for the UDL checkpoint operationalizations).

All four of the curricula were developed with knowledge of common student ideas and difficulties in mind, however, they require students to possess, remember, and readily identify the relevance of and use background knowledge. Inequities in background knowledge exist between students that can inhibit their learning of new concepts. For example, English-language learners may have difficulties understanding the numerous salient terms in physics problems. Also, novice students typically have not built up the complex network of understanding required to determine what is the salient background knowledge required to solve problems. Both the inequities in background knowledge and ability to determine relevance of background information can be reduced by explicitly activating or supplying background knowledge.

As an example, the following is a question from the Tutorials curriculum:

> *A copper wire loop is placed in a uniform magnetic field as shown. Determine whether there would be a current through the wire of the loop in each case below. Explain your answer in terms of magnetic forces exerted on the charges in the wire of the loop.*
> - *The loop is stationary.*
> - *The loop is moving to the right.*
> - *The loop is moving to the left.*
>
> [37] *(p. 125).*

This problem is the first in the Lenz's law activity, which is the first in the electromagnetism section. In this problem there are numerous terms that students need to identify as salient, understand, and use to solve the problem. These terms include uniform magnetic field, current, magnetic force, and charges. In order to solve the problem and fully understand the comparisons that the three different orientations provide, the students must be fluent in these salient terms. In this problem the relevant background knowledge (i.e., the salient terms) is not activated or supplied for students. Thus, this example is unaligned with checkpoint 3.1.[2] While allowing students to build up their own understandings of physics concepts is a good pedagogical practice, UDL allows us to reduce the barriers (in this case, vocabulary) to access the purpose of the activity.

In order to align with checkpoint 3.1, the following practices could have been implemented:

(1) Add a list of key terms (either explicitly in the text or hyperlinked).
(2) Lead a whole class discussion before students work through the activity priming students to bear in mind the relevant background knowledge.
(3) Refer students to the location where the salient background information was presented (e.g., listing page numbers from the book).
(4) Displaying a concept map introducing the section on electromagnetism to situate Lenz's law in the broader electricity and magnetism context.
(5) Demonstrate the salient concepts via simulations or hands-on demonstrations.
(6) Use appropriate analogies or metaphors to describe the relationships between the salient variables.

These practices can help students who do not possess the relevant background knowledge and cannot readily identify which pieces of knowledge are relevant. If the curricula were to implement such strategies, they would be aligned with UDL checkpoint 3.1.

It can be assumed that the background knowledge required to complete the assigned tasks may have been introduced external to the printed curricula (e.g., instructor's whole class verbal instructions at the start of class or feedback during activities), but new information can be more easily assimilated if it is anchored to previously acquired knowledge. Therefore, background knowledge should be supplied and activated for the student more consistently in physics curricula.

A seminal example of an instructional strategy aligned with Checkpoint 3.1 is Clement's "bridging analogies," which start with correct ideas students possess as "anchoring intuitions" and use interventions to bridge those correct ideas to the new context [55]. For example, the OST tutorial on electric fields first has students consider a "wind field" and the effect of various wind fields on kites of various sizes.

#### *3. Providing multiple means of engagement*

The providing multiple means of engagement principle (checkpoints 7.1 through 9.3) was not well aligned with any of the four physics curricula, with the exceptions of checkpoints 8.3 (foster collaboration and community, discussed in Sec. IV. A) and 8.4 (Increase mastery-oriented feedback, discussed in Sec. IV. C). This guideline describes and supports the varying affective needs of learners including the various means of motivating and maintaining the interest of students over time. Overall, variations in the ways in which students are engaged in the learning process are not encouraged and/or allowed in any of the four physics curricula. The curricula do not attend to students' affect and variations in interest, motivation, self-regulation, and perceived challenge. (See Sec. IV. C for more information about how to address these issues in a classroom setting.)

### C. Suggestions for modifications and future curricula

Black and William state "Teachers will not take up ideas that sound attractive, no matter how extensive the research base, if the ideas are presented as general principles that leave the task of translating them into everyday practice entirely up to the teachers" [56] (p. 146). Thus, this section is devoted to suggestions for modification to existing curricula and for future curricula such that they will align with the UDL guidelines and better support the variety of needs, abilities, and interests of students.

We advocate for steady progress toward making the physics community accessible. Making introductory physics curricula completely aligned with all 31 UDL checkpoints immediately is an overly ambitious goal. Instead we urge curriculum developers to identify some suggestions they feel they can readily implement and to make those changes. As more people implement accessible practices over time, the community can move toward supporting diverse students. We also suggest that this be a collaborative effort as, similar to learners, curriculum developers also vary in abilities, needs, and interests.

[2] The same reasoning can be applied to less complex content (e.g., velocity).

#### 1. Provide curricular materials in digital format

Curriculum developers should make curricular components available in a digital format. Both the OST and Next Gen PET curricula are in a digital format, which aligns them with checkpoint 1.1 (offer ways of customizing the display of information). Giving students the curricular materials in a digital format allows students to customize how the information is presented to them by, for example, supporting the use of text-to-speech and text-to-Braille, changing the font and size of text, sequential highlighting, and variations in the timing of information release. Allowing for the customization of information will especially benefit students with visual impairments. Having digital copies of the curricula available would also promote understanding across languages (checkpoint 2.4) by allowing for the use of multiple language dictionaries. Universities are required to provide students course materials in an accessible manner. Having the materials available digitally supports the instructors in supporting the students and sends the message that we anticipate students who need flexible materials in our courses.

#### 2. Assistive technologies

Checkpoints 1.2 and 4.2 specifically relate to assistive technologies for students with physical impairments. The Individuals with Disabilities Education Act (IDEA) defines an assistive technology as "any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of a child with a disability" [57]. These assistive technologies were not discussed in any of the four selected curricula and can especially help students with physical disabilities such as hearing, visual, mobility, and motor skill disabilities. Curricula should include examples of alternatives to the technologies required in the curriculum in the instructor guides. For example, if an activity requires the use of a computer, the instructor guide could provide information about compatibility with alternative keyboards and screen reading software (which allows for text on a computer screen to be read aloud). Although these accommodations are required by most university disability services offices in accordance with federal law (Americans with Disabilities Act and Rehabilitation Act), we should be more cognizant of and intentional in our inclusion of all students and their needs [21,22]. Curriculum developers can better support instructors by explaining how their curricula can be made accessible.

#### 3. Explore and incorporate varied means of representation

Another relatively simple change to future curricula is related to the diagrams presented in the text. More diagrams that accompany the text should be presented as a way to illustrate key concepts and ideas through multiple media (checkpoint 2.5). While many physics textbooks present key information in multiple media (e.g., text, diagrams, graphs), the OST and PbI curricula almost exclusively present information via text. The more diagrams that accompany the text, the more opportunities for students to understand the material.

Additionally, when diagrams are presented they should be accompanied by descriptions of the salient features. This would allow for alternatives to visual information for students, for example, with difficulties interpreting diagrams or those who are visually impaired (checkpoint 1.3). Some students learn best through diagrams, some through text, and some through listening to speech. The more variation in the presentation of information the better to support all students, especially those with specific difficulties with interpretating specific presentations of information, such as dyslexia and dyscalculia. We suggest that key information in the physics curricula be presented via text, diagrams, and as many other methods as is feasible. For example, in addition to the traditional presentation of concepts in the main body of the text, a diagram, graph, and video could be provided (with the additional requirement that the nontext representations have text descriptions and the dialogue in the video be transcribed). These types of supports are likely most easily made during the creation of the curriculum, as such representations can support the developer in the creation process (e.g., a prewritten transcript can be read to create the audio for a video).

#### 4. Vary methods of response and navigation

Checkpoint 4.1 was unaligned with all four of the selected physics curricula. In the curricula, students are required to write (and sometimes speak) their responses to questions which can disproportionately limit the ability of students with disabilities (e.g., dysgraphia, physical disabilities) to respond. The curricula do not allow for variations in response methods such as typing responses in a computer or expressing answers through more creative means (e.g., storyboard or diagram). Also, navigation through the classroom and with classroom objects (e.g., computers, materials required for experiments) is not discussed in any of the four curricula. Gonsalves, Danielsson, and Petterson describe the experience of a female student who encountered difficulty with a scanning tunneling microscope, with which she was typically an expert user, due to her small arm span [58]. This is an example of a common tool not supporting a particular dimension of individual variation. In the classroom, inflexible equipment may be a barrier to learning for students with physical disabilities. Allowances for differences in students' abilities for response and navigation should not be an afterthought added to the curricula as issues arise. Instead they should be built into the curricula with intentionality in order to best serve all students.

#### 5. Optimize individual choice and autonomy

The four selected physics curricula did not provide the students with opportunities for individual choice and autonomy (checkpoint 7.1). Students are required to go through the prescribed steps without deviation and are not allowed to choose the level of challenge, type of feedback given, context for practicing skills, or sequence of tasks. Allowing students a reasonable amount of choice and autonomy in the classroom can increase their motivation about learning physics and their engagement in the learning process [10]. In a physics classroom, allowing for student choice and autonomy could look like allowing students to choose between multiple types of activities (e.g., worksheets, small-group discussion, large class discussion or experimentation) or tweaking the context of problems to be relevant to students' interests or future careers. We advocate for allowing a reasonable amount of choice and autonomy to students in introductory physics courses to increase student motivation and engagement in the course.

#### 6. Optimize relevance, value, and authenticity

The four curricula did not optimize the relevance, value, and authenticity of the physics content covered in the courses (checkpoint 7.2). Students are more likely to be engaged by information and activities that they view as relevant, valuable, and authentic to their personal interests and goals. Presenting physics content in interesting and relevant ways to all students can be challenging because the contexts students find interesting and relevant vary. The UDL framework suggests that the contexts should be personalized to learners' lives, culturally and socially relevant, age and ability appropriate, and appropriate for varying racial or ethnic, cultural, and gender groups. This could be done by changing the context of the problems students are asked to solve, by inviting personal response and reflection to the content and context, or by communicating the connection with the course content and students' interests and goals.

It may be surprising that checkpoint 7.2 was not well represented in the curricula as it aligns with the characteristics that "problems are posed in a wide variety of contexts and representations" and "instruction frequently incorporates use of actual physical systems in problem solving" which are common features of research-based active learning methods [28]. However, the NEXUS physics curriculum provides an example of how contexts relevant to biology students can be integrated into a physics course [59].

#### 7. Heighten salience of goals and objectives

Only the Next Gen PET curriculum was aligned with checkpoint 8.1 (heighten salience of goals and objectives) because a key question was listed for each activity. This is a shallow alignment and could be improved by referencing and restating the goals and objectives of each activity for students as they progress through the activity. Clearly explicating the goals and objectives of an activity can help students persist in completing a task and with sustaining their interest. Formally stating the goals at the start of an activity can also help students to frame the activity in their minds to allow for maximization of learning and connections between previously covered material. Therefore, we suggest that the goals and objectives for each activity be clearly stated at the start of and throughout each activity.

#### 8. Increase mastery-oriented feedback

Checkpoint 8.4 was highly aligned with the OST curriculum but no alignment was identified for the other three curricula. All of the activities in the OST curriculum were aligned with this checkpoint because the curricular materials discuss how to give differentiated feedback (i.e., individualized feedback to meet each students' needs). This differentiated feedback constitutes mastery-oriented feedback. The Center for Applied Special Technology (CAST) states that mastery-oriented feedback "guides learners toward mastery rather than a fixed notion of performance or compliance" [10] (p. 32). This notion is related to the growth mindset as described by Dweck [60]. This type of feedback can help students sustain their interest and engagement as well as impart the notion that effort is more important than incoming intelligence [60]. Emphasis on progress toward mastery can be especially important for students with disabilities whose disabilitiy can be interpreted as limiting and their ability as limited [10]. On the other hand, the PbI, Next Gen PET, and Tutorials curricula state that instructors should be monitoring student progress and discussing students' work throughout the class period, but do not discuss the type of feedback that should be given to the students. Future physics curricula should include instructor guides that provide information about and implementation examples of mastery-oriented feedback; the OST instructor guides provide an example of how this can be done.

## V. IMPLICATIONS

The purpose of this study was to investigate the accessibility of research-based physics curricula via their alignment with the UDL framework. Thus, we make claims solely about the accessibility of the curricula and not about their overall quality. Many studies have demonstrated that these curricula are valuable on dimensions such as student learning (see Refs. [39,41,43]) and students' attitudes and beliefs (see Refs. [39,44]). Instructors must engage in a balancing act when selecting a curriculum, considering possible conflicting factors such as content coverage, instructional design, and cost to the student. We argue that accessibility should be included in the list of curricular factors to consider.

The burden of making physics courses accessible to and supportive of all students does not fall on one group of stakeholders but instead is a community effort. We view the stakeholders involved in creating supportive classroom environments to include the following: curriculum developers, instructors, campus disability or accessibility services offices, administrators, and funding agencies.

Curriculum developers should design materials and products that provide options for access and support diverse learners. Instructors should demonstrate a belief that all students belong and can succeed in a given class. They should also participate in training opportunities to expand their understanding of how to support all students, select and implement accessible curricular materials, and provide individual accommodations as needed. Campus disability or accessibility services offices should provide accommodations for students with individual needs and support faculty in meeting those individual needs. Administrators should promote a culture of inclusion at the campus community, department, and courses levels. They should also provide training about accommodations and accessibility for instructors and staff. Funding agencies should encourage curriculum developers to make their curricula accessible. All of these stakeholders should be held accountable for making physics courses accessible to and supportive of all students.

The UDL framework is intended to assist with the design of curricular materials. Thus, we will further discuss implications for curriculum developers and funding agencies below.

### A. Curriculum developers

Learners vary in their abilities across a broad range of skills. Therefore, if we want to be inclusive of all students in the physics classroom, the curricula should be developed to support learners who all inherently vary in abilities, needs, and interests. Curriculum developers should be cognizant of these variations when developing new curricula and when revising existing curricula. By building plans for supporting students with disabilities into curricula from the start, we demonstrate that such individuals are welcome and anticipated to participate in the physics community. Curriculum developers should also provide documentation of critical features that promote access and compatibility with accessibility technologies for future adopters of the curriculum. Since curriculum developers vary in terms of their abilities, needs, and interests, they should partner with others in the physics community as well as experts in accessibility to create accessible curricula.

### B. Funding agencies

Funding agencies should support curriculum developers by providing the necessary resources for developers to focus on accessibility and to enable partnership with accessibility experts. If steps are not taken to ensure that future curricula are aligned with the UDL guidelines, we will continue to send the message that not everyone is expected to participate in the physics community and continue to put faculty at risk of violating federal law.

## VI. FUTURE WORK

Future work should focus on investigating the digital components of the curricula. While making the curricula available digitally allows for the customization of the display of information, there are some digital formats that are more accessible than others. There is an online tool that assesses the accessibility of websites called the Web Accessibility Evaluation Tool (WAVE) [61]. This tool scans websites and other digital documents for multiple facets of accessibility, including compatibility with accessible keyboards and screen readers, visual accessibility, and structural elements of the websites that aid in accessibility. Future work should focus on determining the accessibility of existing digital curricular components and on making suggestions to improve the accessibility of future curricula.

Another avenue of future work is exploring alternate representations of information for learners with perceptual difficulties. Sayhun has started work in this area by developing methods of sonification of data and tactile representations of surfaces for visually impaired learners [5,62]. This is an important step toward making information accessible to all learners. However, research should also focus on how such tools are used by a variety of students. For example, Harshman, Bretz, and Yeziersk found that accommodations produced by sighted researchers could be overwhelming for learners who are blind or who have low vision [63]. Thus, future work should investigate alternate representations of information and how these alternatives are used by a variety of students.

## VII. HELPFUL RESOURCES

For more information about the Universal Design for Learning framework see, Ref. [64].

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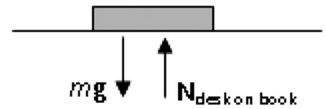
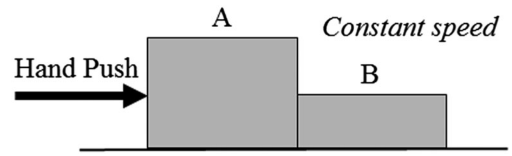
## APPENDIX

This Appendix provides an example of each Universal Design for Learning checkpoint that was identified in the curricula chosen for this study.

TABLE V. Universal Design for Learning checkpoint seminal examples.

| Checkpoint | Common alignment criteria | Seminal examples |
|---|---|---|
| 1.1 | Digital copies allow for customization | PDF and Word documents |
| 1.2 | Provide ASL translation, written copies of verbal instructions, etc. | See Supplemental Material [46] |
| 1.3 | Diagrams include descriptions with all salient features to complete problem |   (OST, ILD 3) |
| 2.1 | Define vocabulary or symbols | "Light from the source reaches the object and then travels from the object to the observer's eye. We say that light from the source is reflected from the object." (PbI, Vol. 1, pg. 228) |
| 2.2 | Define/clarify structure of equations or steps in a process | Steps of Engineering Design process are explained and used to structure activities throughout the course. (PET) |
| 2.3 | Helping students understand and decode mathematical notation. | See Supplemental Material [46] |
| 2.4 | Link to non-dominant language dictionaries, include definitions in non-dominant languages, etc. | See Supplemental Material [46] |
| 2.5 | Diagrams or graphs used to help explain/clarify key concepts |   "Three identical bricks are pushed across a table at constant speed as shown. The hand pushes horizontally. (Note: There is friction between the bricks and the table.)" (Tutorials, page 31) |
| 3.1 | Reminding students of previously covered concepts or equations or referring to previous activities. | "By checking for coherence with Newton's 2nd law ($F_{\mathrm{net}} = ma$), we can narrow down the list of possible free-body diagrams." (OST, ILD 5) |
| 3.2 | Highlight salient information via italics, bolding, or font changes to emphasize key elements. | "The process of finding the area under a graph is called *integration*. For a v versus t graph, the resulting number is called the *integral of the velocity over time*." (PbI, Vol. II, page 716) |
| 3.3 | Give explicit prompts for each step in an activity (not just questions in activity). | Breaks problems down into steps in a process (PET Unit M, Activity 1) |
| 3.4 | Allow opportunities for review and synthesis of physics topics. Or generalize physics concepts to new situations. | Engineering design activities take the physics content learned in the activities and apply them to real world situations. (PET) |
| 4.1 | Allow students to respond to questions in formats other than writing. | See Supplemental Material [46] |
| 4.2 | Provide assistive technologies for students such as alternative keyboards. | See Supplemental Material [46] |
| 5.1 | Request students to show their understanding in a myriad of media such as text, speech, etc. | "Draw an extended free-body diagram for each spool at an instant after they are released but before they hit the floor." (Tutorials, page 62) |
| 5.2 | Provide calculators, graphing paper, speech-to-text software, etc. for students to construct or compose their responses. | Not identified in curricula |
| 5.3 | Provide differentiated feedback that is customized to the individual learners. | "Make sure they understand what slope is (not to be taken for granted, even for students that have taken calculus!) Be sure to ask each group member questions. Just because one student understands the graphs doesn't mean that all four students follow that reasoning. Sometimes the quietest students need the most help, and a diagnosis is required." (OST, Tutorial 1 Instructor Guide) |

*(Table continued)*

TABLE V. *(Continued)*

| Checkpoint | Common alignment criteria | Seminal examples |
| --- | --- | --- |
| 6.1 | Provide guides and checks to support and scaffold goal-setting. | See Supplemental Material [46] |
| 6.2 | Prompt students to stop and show/explain work. | "Two different linear resistors, A and B, have the same voltage across them. If the currents through the resistors are 5 A and 4 A, respectively, what is the ratio of the resistances? Explain your reasoning." (PbI, Vol. II, page 467) |
| 6.3 | Provide templates for data collection and organization of information. | "In your notebook make a table like the one below to record your observations from part A-C. Use a word or phrase to describe the interactions." (PbI, Vol. 1, p. 278)<br>Table of Interactions<br>Class 1 Class 2 Class 3<br>Class 1 _______ _______ _______<br>Class 2 _______ _______ _______<br>Class 3 _______ _______ _______ |
| 6.4 | Ask questions to guide self-monitoring and reflection. | "Are you 100% comfortable with your understanding of this scenario, or is there still something that needs to be reconciled? Explain." (OST, Tutorial 3) |
| 7.1 | Provide design activities where students choose level of challenge, materials, timing of completion of tasks, etc. Also, provide choice in which components of activities must be completed. | Engineering design activities allow students to participate in design of activities, and allow students choice in activities. (PET) |
| 7.2 | Choose activities that optimize the relevance of curriculum to students' lives and invite personal response to content and activities. | "Lying on the floor is even more comfortable than lying on a bed of nails. Why? Draw a diagram to illustrate your answer." (PET, Tutorial 8) |
| 7.3 | Create an accepting and supportive classroom environment for all students. | Not identified in curricula |
| 8.1 | Goals and objectives for each activity are listed. | "The key question for this lesion is: How can we trace the flow of energy through a system of interacting objects (including the surroundings)?" (PET, Unit EM, Activity 5) |
| 8.2 | Provide alternatives for tools and scaffolds required to complete activities. Or vary the standards for acceptable performance. | "Some students will predict this "start-up curve" on the graph and some will not. Depending on when they start the detector they may get disagreement between their prediction and the experiment. This "mistake" can be good for students to discuss, but it can also cause great confusion and eat up a lot of time. Individual diagnosis/discretion by the instructor is called for here." (OST, Tutorial 1 Instructor Guide) |
| 8.3 | Create groups with clear roles and responsibilities. | "Students work together in small groups, constructing answers for themselves through discussions with one another and with the tutorial instructors." (Tutorials, preface) |
| 8.4 | Provide and encourage mastery-oriented feedback. | "Second, ask about their mistake catching. They should have multiple discrepancies between their predictions and experiments. Talk with the students about these discrepancies and why they occurred." (OST, Tutorial 1 Instructor Guide) |

*(Table continued)*

TABLE V. *(Continued)*

| Checkpoint | Common alignment criteria | Seminal examples |
| --- | --- | --- |
| 9.1 | Give activities that promote self-reflection and setting of personal goals. | See Supplemental Material [46] |
| 9.2 | Provide models and feedback for managing frustration. | See Supplemental Material [46] |
| 9.3 | Promote monitoring of behaviors or provide feedback about emotional reactivity. | "Electrostatics is tricky, though, and as at the last checkpoint TAs will need to balance competing concerns (including helping students get closer to a correct model, encouraging genuine inquiry, holding students accountable for consistency and coherence in their explanations, and keeping students from getting frustrated)." (OST, Tutorial 3 Instructor Guide) |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