A student-centered research project on correcting misconceptions in introductory physics: A metacognitive intervention supporting conceptual change

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Student misconceptions in introductory physics topics are widespread. This study investigates a project in which students are required to research how other students deal with misconceptions that arise when engaging with these topics. Six topic areas, well-known by physics education researchers for the difficulties students encounter when they engage in these areas, are presented as research topics. Students select for their research one of the topics that they personally identify with, either through their own struggles, or from observing others, or both. Students conduct research and present their findings to the class citing two additional and relevant peer-reviewed sources. They complete pre- and post-project surveys, a written reflection on their own experience, and answer interview questions similar to those presented in the Colorado Learning Attitudes about Science Survey (CLASS). Preliminary results suggest that this project encourages deeper engagement and helps students correct misconceptions, improving their conceptual understanding of key physics concepts.

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I. INTRODUCTION

This paper reports on a pedagogical approach that makes use of a novel metacognitive intervention. In this intervention, students are given a reading list of peer-reviewed articles on common misconceptions that introductory physics students often encounter. From this list they are asked to select an area of misconception, research it more deeply, and then report their findings in an end-of-term project which requires that they present their findings as a team to the class. In the following sections, we describe in detail the elements of the intervention, and the corresponding results of discourse analysis of the transcripts from post intervention student surveys, written summary/reflection essay, and student interviews which provide evidence that the intervention supports conceptual change and increased student sense-making. We also provide results of pre/post epistemologies as measured from the Maryland Physics Expectations Survey (MPEX data) [1]. We believe the results will be useful to instructors who may consider similar interventional approaches to their existing pedagogy [2].

We take the position that this research is important and that results from the research could be impactful in terms of building on a student's conceptual base. Student misconceptions are extremely common in introductory physics [3]. Not only do students struggle with ideas that are often in opposition to their direct observations, but they also have to unlearn vocabulary that often carries a different meaning in the physics classroom than in everyday language. The metacognitive intervention that we administered was inspired by the notion that allowing students to have their misconceptions, also referred to as preconceptions or "conceptions in progress" [4], leaves room to facilitate their mistaken ideas as "necessary stepping stones" for "a path toward more accurate ideas about the natural world" [5,6].

II. A METACOGNITIVE INTERVENTION

This project requires students to research common misconceptions that *other* students have, much like themselves, when taking their first introductory physics class, giving students the opportunity to learn about their own learning by exploring other students' experiences. The project is assigned to the students about seven weeks before the term ends. They work in self-selected groups of two or three members and present their research in a 7–8-minute presentation at the end of the term. For the content of their presentation, student groups select one misconception area to research from the following list of commonly held misconceptions related to 1) force, 2) kinematics 3) momentum and collisions, 4) friction, 5) mass vs. weight confusion, 6) language and physics vocabulary. In addition to the peer reviewed articles provided, students are also required to find at least two more peer reviewed sources, for a total of four sources, which will inform their presentation. Students are to select a topic that resonates with them as a group or that they identify with based on their experiences in this course. A portion of their presentation requires them to share personal reflections on why they identify with or were otherwise drawn to their topic choice. In addition to the group presentation portion of the project, students must also submit an annotated bibliography about their four peer-reviewed sources, along with a 500-word summary/reflection essay in which they were asked to articulate their personal connection to their chosen misconception. This part of the project is done individually, allowing students to reflect on their learning and connection to the topic outside of a group context.

III. METHODOLOGY

Students enrolled in a large enrollment, calculus based, introductory physics class that utilized active engagement pedagogies were given a choice of topic categories in which to explore various misconceptions. For this study, to guide their explorations, we provided the reading list shown in table 1. Students were also given two full 90-minute discussion periods to work with their group exploring the established research, finding additional peer reviewed literature, and creating their presentations with guidance from their discussion TA. They were also allowed this time to develop their annotated bibliographies and to discuss their personal reflections in preparation for turning in their 500-word summary/reflection essays. We advised students to set aside an additional 8-hours outside of class time to collaborate with their group and work independently. We note the following overall timeframe: The summary/reflection essay was due the evening prior to the presentation, while the presentations were made at the final class meeting. The post intervention surveys followed within two days of this last meeting, and the student interviews were concluded within three days of the last class meeting.

TABLE I. Peer-reviewed Articles Provided to Students

Misconceptions about:	Reference
Force	[7], [8], [9], [10]
Kinematics	[11], [12], [13], [14]
Momentum	[15], [16], [17], [18]
Friction	[19], [20], [21], [22]
Physics vocabulary	[23], [24], [25], [26]
Mass vs. weight	[27], [28], [29], [30], [31]

We used both qualitative and quantitative tools to measure student experiences for various components of this project. In particular, we used three sources of qualitative data: 1) we administered an anonymous post intervention survey with a 48 hour post presentation due time to ensure that responses were fresh, 2) we collected the 500-word summary/ reflection essay that students submitted prior to their presentation, and 3) we engaged in one-on-one interviews with a small, self-selected population of students, based on their interest and time constraints. We used interview questions that were inspired by specific CLASS questions that were closely aligned to probe students' sense-making

tendencies, specifically asking students about their learning, understanding, reasoning and relating skills (see section V.C). For a quantitative component, we administered the MPEX pre/post survey tool to measure epistemological shifts.

A. Post intervention survey

The anonymous post intervention survey contained two sections. In the first section, we asked the following: "Did you learn something or gain a new or clearer understanding of some physics principles/concepts from today?" Students rated their agreement with this statement on a 1-4 scale. In the second section of the survey, we asked students to elaborate on their answer by stating specific "take aways" and providing examples of what was learned or how a specific concept *changed* because of doing and watching the presentations.

B. 500-word summary/reflection essay

Students were prompted as follows: "Please select, identify and explain a specific misconception topic that you have encountered during the teaching and learning of this introductory physics class. Be sure to include a personal connection with the misconception that you are researching and provide a detailed reflection on how doing this research helped you to bridge the misconception or, if you did not have this misconception personally, how did the project enhance your understanding of this misconception more generally. There is a 500-word length requirement."

C. One-on-one student-instructor interviews

Three days after the presentations were concluded, one-on-one interviews between the instructor and a set of seven volunteer students were conducted. During these interviews, six statements were taken from the CLASS survey and proposed to students for feedback. The interviews lasted approximately 20 minutes. To get students to expand on their ideas, probing prompts like "What makes you feel that way" or "Did you ever change how you felt about that during the semester, if so, when?" were asked as follow-up questions.

D. MPEX pre and post survey data

The standard MPEX survey was given to students as a pre/ post survey before and after the intervention in search of evidence of epistemological shifts. We used the Phys Port Data Explorer for scoring and analysis.

IV. A LINGUISTIC CODING SCHEMA

Each of the three qualitative project components were analyzed using discourse analysis. The use of discourse analysis – transcribing and coding student language both verbally and written – is a well-supported methodology for gaining insight into how students make sense and meaning with a long history in science education. Ever since Lemke's seminal work, that "learning science means learning to talk science" [32], researchers have taken the position that students' language, gestures, talk-aloud protocols and written and verbal texts [33, 34, 35, 36] mediate thought into meaningful expression. From this, they have used discourse analysis to measure cognitive processes such as conceptual change, knowledge construction, and sense-making in these student texts. More recently, discourse analysis has moved from narrative interpretation of student language to clearer coding criteria, expanding to include specifics, as we have done here, such as counting and analyzing phrases, clauses, and lexical themes, and using various linguistic constructs to develop a more exacting framework for coding [37, 38, 39].

For deductive coding schemes, we looked for specific linguistic evidence in the student responses (transcripts) from all three qualitative data sources that correlated with experiences that modeled commonly accepted descriptions of conceptual change and sense-making. For inductive schemes, we reviewed those transcripts again, looking for repeating and/or common language, ideas and phrases that we could categorize. This enabled us to develop a robust scheme based on theory as well as emergent themes.

A. Informing deductive coding categories

Early models of conceptual change are described as enrichment of an existing concept through the addition of new information to an existing conceptual framework [40]. However, research in this area, specifically attempting to define conceptual change, has evolved over time. This is largely due to differences in perspectives and variations in key definitions, leading to a more recent characterization of conceptual change as "contested and messy" [41]. Nevertheless, despite vastly divergent models of conceptual change, the idea that learners must, at some level to some degree, change their existing knowledge remains a reasonable idea. Adopting this perspective, we took linguistic cues that acknowledged a change in thinking or perspective, i.e., 'before and after,' as reasonable evidence of conceptual change. For example, phrases in the transcripts that were structured as follows were coded as *conceptual change*: "After completing this project/activity I was able to," or "I previously thought that A, now I think B," or "beforehand I thought A, now I think B," or "before the presentation I understood x, now I understand y."

Sense-making, on the other hand, is not just a cognitive activity, involving the construction of explanations and descriptions [42], but also a deeply epistemological one. How students frame a task depends on their personal epistemologies for what it takes to learn/be successful in physics [43]. Are they taking a particular task as an opportunity to dig deeper for understanding as opposed to Plug-n-chug [44]? From this we took linguistic cues supporting "digging deeper," or any descriptions of the way in which they framed or approached problems, as reasonable evidence of attempting to "make sense." So, for example,

phrases that were structured as follows were coded as *sense-making*: "I took steps," "I modeled," "I reframed/broke down/pulled apart/made connections", "I was thinking in new ways".

B. Informing inductive coding categories through emergent patterns and themes

We reviewed the transcripts again, this time focusing on emergent patterns and themes, we discovered that students often provided details regarding the degree to which observing, watching, and listening to the presentations helped them come to terms with their misconceptions. Social cognitive theory [45] supports this idea that individuals can acquire new behaviors by observing others. In this case, learning by observation, especially by observing peers, is not just copying alone, it involves attention, retention, reproduction, and motivation. Through a process of self-efficacy, watching peers succeed increases an individual's belief in their own ability to be successful and can make peer observation a powerful tool in learning environments. From this we took any linguistic cues that acknowledged learning from observation as reasonable evidence of *construction of knowledge through observation of peers*. Following are examples of phrases captured in the student transcripts that support this category: "watching the presentations gave me a better understanding/reminded me/convinced me/gave me the ability to see/cleared up/gave me new ways to describe/helped me realize."

Additionally, many students expressed relief in realizing that others shared their difficulties and noted a shift in their self-worth, specifically stating they no longer felt "embarrassed" or "ashamed" of their misconceptions. These explicit phrases were categorized as "*we are all in this together*." Finally, we noted that in the transcripts student frequently reflected on how the research project helped them develop new skills, and that they were planning on utilizing these skills in future classes, future activities, and even future conversations with their friends. This led us to create and code for an additional category entitled "*skill building*."

V. CODING RESULTS

In this section, we summarize the results of coding the three qualitative components of the research project. We include the following: A) post intervention survey results, B) 500-word summary/reflection essay results, and C) student interview results. In each of these components, we searched for the linguistic cues described in the previous section and categorized those cues as shown in table 2. Coding consistency was evaluated using percent agreement between two raters who independently coded the submissions. On follow-up, the raters agreed on 95% of the coded segments, indicating strong inter-rater consistency in the application of the coding schemes.

TABLE 2. Categories of Linguistic Cues

Category	Examples of Linguistic Cues
Conceptual Change	Before the presentation I understood X, now I understand Y
Sense-making	I reframed/broke down/ pulled apart/made connections
Knowledge by Observation	Watching the presentations gave me an understanding/reminded me/gave me the ability to see/cleared up/gave me new ways to describe/helped me realize
We are all in this together	Physics misconceptions are very common/I don't feel so ashamed anymore/ We are all in this together
Skill-building	Now I will use my graphing skills in my future chemistry lab classes

A. Post intervention survey results

We transcribed and coded the free-response portion of the anonymous post intervention survey for 69 students as shown in fig. 1. Linguistic cues largely supported evidence of *conceptual change*, *sense-making* and *knowledge building from observing others*. For example, one student's response showed that they were making connections between the different misconception topics presented by saying, "It is important for students to have a clear understanding of friction, mass, kinetic energy, all before learning momentum. In physics the concepts build off each other to solve certain problems regarding physics and momentum."

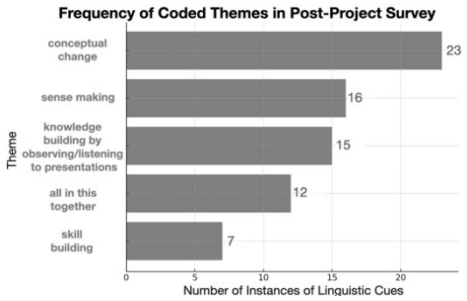

Figure 1. Data from coding the post intervention survey.

B. 500-word summary/reflection essay results

We transcribed and coded 60 500-word student summary/reflection essays as shown in fig. 2. In this data, we find good evidence in support of conceptual change. We observed that students were commonly either correcting their misconceptions or filling in gaps of knowledge because of the intervention. Statements indicating conceptual change, such as: "I now realize that an object's mass, which is a measure of its matter content, is constant everywhere in space, and weight is the force that gravity applies to that mass, and it varies according on the gravitational field's strength." were found in *all* student essays we coded.

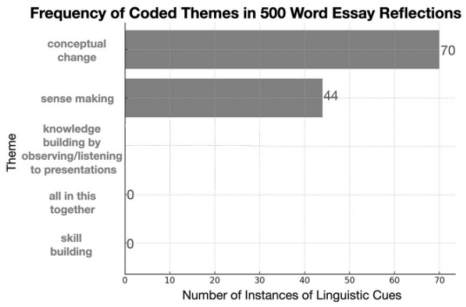

Figure 2. Data from coding the 500-word essays. Knowledge building by observing/listening to presentations had 0 instances as the reflection essay was due prior to the presentation.

C. Student interview results

Seven students were interviewed, and their responses were transcribed and coded as shown in fig. 3. To guide the student interviews, participants were prompted with six statements adapted from the CLASS survey and asked to expand on their views, agree or disagree, for the following statements: 1) I cannot learn physics if the teacher does not explain things well in class, 2) to understand physics I discuss it with friends and other students, 3) In physics, it is important for me to make sense out of formulas before I can use them correctly, 4) reasoning skills used to understand physics can be helpful to me in my everyday life, 5) there are times I solve a physics problem in more than one way to help my understanding and 6) when studying physics, I relate the important information to what I already know rather than just memorizing the way it is presented. In our analysis of the transcripts, we found that students were able to provide deeper insight supporting *why* they think the way they do. This led to much more evidence of *sense-making* in their responses. We see many responses like: "If I can relate it to what I already know, then I might be able to connect what I'm learning with things that I've learned in the past, so it might help me understand it more than just trying to memorize it."

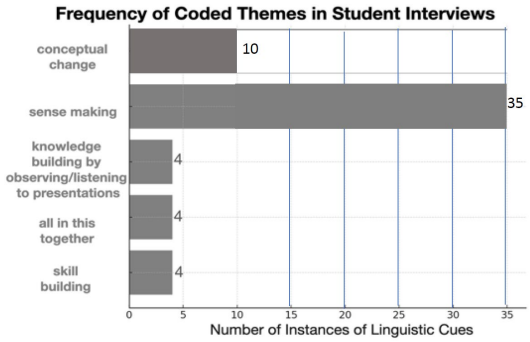

Figure 3. Data from coding the student interviews.

VI. MPEX PRE/POST SURVEY RESULTS

The PhysPort Data Explorer was used to analyze the responses to the MPEX pre- and post- surveys for 52 students. No statistically significant change in student epistemologies were found. In typical physics classes students' beliefs often deteriorate, and for active engagement large enrollment classrooms, t at best stay the same, towards responding in a manner consistent with "expert-like" beliefs [1]. We note our results are in-line with many courses that have adopted some form of active engagement to address student expectations and beliefs. [46].

VII. DISCUSSION AND CONCLUSIONS

In reviewing our results, we believe that analysis of all three of our qualitative data components conclusively show that sense-making, conceptual change, and construction of knowledge have been positively supported with this intervention. We take note that each data component shows a different dominating cognitive process. The post intervention survey and the reflection/summary essay results for example tend towards conceptual change as the predominant process, while the interviews tended towards sense-making. We believe that the structure of the prompts are partly responsible for these trends. For example, prompts for the reflection/summary essay and the post intervention survey, elicited writing about personal experiences, opinions, or personal takeaways. These tasks require strong familiarity with the topic and thus result in greater lexical diversity, which may explain the higher frequency of "explaining what changed" in both qualitative components [47].

Alternatively, the interview transcripts provided evidence of a positive shift toward sense-making attributed to the intervention. The interview questions were chosen largely to prompt students to reflect on whether they shifted toward or away from sense-making strategies in their beliefs about learning physics. The greater instances of sense-making language are in line with what we might expect, and additionally, all seven students showed a positive shift toward sense-making strategies. In this way, the interviews provide evidence for the intervention having a positive impact on student beliefs and expectations which have been shown to correlate with sense-making language [34]. Of interest is the fact that some student comments could point to answer-seeking tendencies, rather than sense-making tendencies, but the overall sample size for the interview portion was insufficient for statistical conclusions. For our next steps, we plan to broaden our interview numbers and to develop a more comprehensive and targeted survey to tease out sense-making tendencies versus answer-seeking tendencies.

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