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Using Brain-Based Interventions to Address Ninth Grade Students' Misconceptions about Newton's Laws: Descriptions of Secondary Teachers' Action Research

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A longstanding issue of challenge among physics educators is that students' misconceptions about physics concepts are highly resistant to modification (Hart, 2002; Montfort et al., 2007). A number of studies have identified the effectiveness of implementing constructivist pedagogy to address misconceptions about Newton's laws in the upper high school grades and university level physics classes (Demirci, 2005; Djajati & Mokhtar, 2014; Halim et al., 2014.; Kelly, 2011; Rosengrant et al., 2009; Saleh, 2011; Yeo & Zadnik, 2000). However, very few have looked at addressing the misconceptions of ninth grade students though one study has documented the positive effects of using an inquiry-based approach in an enrichment program designed for eighth grade students (Kelly & Kennedy-Shaffer, 2011). The ninth grade population is of special interest because of the likelihood that a significant number of these students are still in transition from Piaget's concrete to formal operational stages; as such, misconceptions may be particularly difficult to modify (Adey & Shayer, 1990; O'Donnell, J.R., 2011). Therefore, the purpose of the present article is to describe the work of four secondary teachers who conducted action research projects focused on the use of brain-based, constructivist pedagogies in an effort to modify ninth grade students' misconceptions about Newton's laws.

Brain-based teaching involves the application of the principles of how the brain naturally learns to the practice of teaching (Jensen, 2008). Descriptions of pedagogies based in a brain-based approach tend to be constructivist in nature and steeped in research from cognitive psychology. Cognitive neuroscientists have proposed that decisions about pedagogy take into account how the reactive brain, including the reticular activating system and the limbic system, can block the further processing of sensory data by the prefrontal cortex, thereby interfering with learning (Willis, 2010). Few studies to date have described the systematic use of brain-based interventions in physics education. In one such study, the use of seven brain compatible instructional phases resulted in positive effects on students' learning and motivation compared to traditional instruction given to a control group (Saleh, 2011). These steps included activation, establishing the outcomes and the big picture, making meaning and connections, doing a learning activity, demonstrating student understanding, reviewing for student retention, and previewing the next topic.

Since brain-based pedagogy represents a departure from traditional teaching methods, enabling teachers to take ownership of this approach in a reflective manner is imperative. A powerful way to promote ownership and reflection is by preparing teachers in how to conduct action research (McNiff, 1996)). Action research has been described as a cyclical approach consisting of teachers deciding the intervention, planning the action, doing the action, reflecting on the action, and sharing the learning (Grant et al., 2010). While there is a growing literature describing secondary physics teachers' action research, most of these endeavors describe the studies of teachers conducted in countries other than the United States (Djajadi & Mokhtar, 2014; Grace et al., 2015). One exception is the work of the PER group at Rutgers. In one such investigation, the use of action research in addition to scaffolding and formative assessment improved students' scientific abilities over a three-year period (Etkina et al., 2009).

Method

Participants

After attending a summer workshop offered for graduate credit on the topic of brain-based learning that featured a module on action research, four secondary physics teachers planned and conducted action research projects for the spring semester of the following academic year. All of the physics teachers taught ninth grade physical science classes in secondary schools located in the mid-Atlantic region. Of the four teachers, there was one female and three males. In each case, the teachers taught

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students enrolled in introductory physical science classes; these classes were the first formal exposure to physics for the students and taught in a block-scheduling format. The four teachers possessed a mean of 4.5 years of teaching experience, ranging from two to nine years. Two of the teachers, Teachers A and B, taught ninth grade physical science in the same large public school district located close to a large urban area; this district was characterized by a highly diverse populace, ranging from low to upper socioeconomic households. A third teacher, Teacher C, taught ninth grade physical science in a large public school suburban district of middle to upper socioeconomic range with little student diversity. A fourth Teacher D, taught physical science to ninth graders at a private charter school in an urban setting characterized by small class sizes and a diverse populace of students ranging from low to middle-income backgrounds.

Procedures

In order to ensure that the data collection was manageable, the four teachers focused their action research on one misconception identified in pre assessment data. The teachers were careful to plan lessons that directly confronted students with their misconceptions, creating a state of cognitive disequilibrium. Teachers also planned to check that students understood the alternative conception and that they worked with real-life examples of the concept, thereby enabling them to reestablish equilibrium (Alparsian et al., 2004). To address these misconceptions, they selected a variety of pedagogical interventions related to making meaning and connections, doing an activity, demonstrating understanding, and reviewing for student retention, several key steps in Saleh's model of brain-based teaching (Saleh, 2011). The interventions occurred over four to six week unit on Newton's laws taught during the third and fourth quarters of the school year. The investigator recorded observational notes based on classroom observations of these lessons to document the use of the planned interventions.

To document the effectiveness of the interventions, the teachers chose a variety of data collection methods including pre and post assessments of student learning, student interviews, student surveys, and student journals. All four teachers assessed student learning and three of the four teachers investigated students' perceptions relative to the interventions by using teacher-developed questions or instruments. As part of the present investigation, teachers completed an information inventory in which they described their action research projects and an open-ended survey about their perceptions of the action research process.

Results

Based on an analysis of the information inventories and an analysis of notes taken by the investigator during classroom observations, descriptions of each teacher's

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action research were compiled. Teachers' perceptions of the action research process were summarized after analyzing teacher responses to the open-ended survey.

Descriptions of the action research

Teacher A possessed nine years of experience; he had been at the same high school for his entire career. Based on two classes of students' pre-test responses, Teacher A ascertained that a common misconception among his students was that in order for something to create a force, it must be in motion or in action, like an object bumping into something else. When presented with scenes that depicted a person jumping on the ground or bouncing on a trampoline, students most commonly did not understand that the ground and the trampoline respond with a force of the person jumping and pushing downward. This misconception is related to Newton's third law, for every reaction force, there is an equal and opposite reaction force. Teacher A decided to utilize slow motion video scenes so that students could observe in slow motion, how force works in several different scenarios. These included showing what happens when billiard balls collide. Another scene featured a person sitting on a cart with wheels and then throwing a box in one direction while still on the cart. Students were required to keep a journal in which they reflected on whether the slow motion video scenes made them think differently about force.

Teacher A compared student responses on pre and post assessments in an effort to investigate how helpful watching the slow motion videos were in facilitating a shift in misconceptions initially discovered in the pre assessment. The scenes on the post assessment were different from the ones used in the pre assessment. Teacher A also collected student journals to analyze their reactions to watching the slow motion videos. Students completed a brief survey, in addition, in which they shared their perceptions as to the helpfulness of the videos and modifications for future use. Teacher A found that whereas very few students initially understood that an object does not need to be in motion to create force, the great majority of students understood this on the post assessment. While nearly all of the students indicated that viewing the slow motion video aided them in better understanding Newton's third law, they suggested creating several novel slow motion videos involving athletes playing sports or the students themselves acting out scenes. Teacher A plans to create additional slow motion videos based on these suggestions.

Teacher B had a total of four years of experience; he worked at his position for the last two years and for two years at a different high school. According to pre assessment data from one section of students, a common misconception Teacher B gleaned was his students' idea that an object needs force to continue in motion. When presented with a scene in which a coin on an index card lies on top of a drinking glass, students commonly believed that when the card is pushed quickly off the glass that the coin stays with the card. They failed to recognize that because the card moves too fast,

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the force of friction does not have enough time to move the coin. This misconception is related to Newton's first law, an object in motion continues in the same motion unless an external force, or friction, acts upon it. After modeling sample demonstrations and having students use the Awesome Ball iPad application, Teacher B had his students work in small collaborative groups to create their own demonstrations of inertia. Students then role played these demonstrations and explained them to the rest of the class. As part of this explanation, students discussed how the activity made them think differently about objects remaining in motion.

In order to assess if the student-created demonstrations activity modified misconceptions, Teacher B compared pre assessment data, consisting of open-ended questions in which students were asked to predict what would happen in sample scenes and explain their prediction, to post assessment data which involved the same format, only new scenarios. Teacher B analyzed student journals for perceptions about the effectiveness of utilizing student-created demonstrations. He found that post assessment data contained more accurate predictions compared to pre-assessment data and more elaborate explanations for the predictions. While most students responded positively to the use of student-created demonstrations, several students suggested making sure that students explain their demonstrations more slowly and in a louder voice so that the rest of the class could understand them. Teacher B plans to continue to employ this activity and evaluate student demonstrations using a rubric.

Teacher C had been teaching for a total of two years at the same high school. Two classes of students responded to several pre-assessment questions modified from the Force Concept Inventory. They also completed a pre-assessment diagram in which students drew arrows that depicted existing forces. Students commonly thought that if an object is sitting, such as a glass on a table, that there is no force acting upon it, so there is no acceleration. Based on an analysis of these data, Teacher C determined that students were unlikely to understand how many forces act on a glass sitting on a table or that the net force involves the force of gravity pulling down on the glass plus the force of the table pushing up on the glass. This misconception is connected to Newton's second law, the acceleration of an object is proportional to the net force acting on the object. In an effort to address student misconceptions, Teacher C had students use the HSVPL iPad application (made by Polyhedron Learning Media) and practice drawing free body diagrams in collaborative groups; students then created their own scenarios for additional diagrams. Each collaborative group was required to write down how their free body diagrams changed from the start of the process. In addition, Teacher C also modeled the second law by using liquid accelerometers.

Teacher C administered a post assessment using modified items from the Force Concept Inventory. She also gave students different free body diagrams as another post assessment in which they drew arrows showing forces present. In addition, Teacher C

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analyzed each group's written explanation as to how their free body diagrams changed from the start of the process until the end. Many more students responded accurately to the post assessment items than to the pre assessment items. Teacher C also found that on the post assessment many more of her students responded correctly to the free body diagram. Teacher C is investigating the efficacy of using the accelerometer function on the iPod touch in future lessons.

Teacher D had taught for three years, all at the same high school. Based on one section of student responses to pre assessment questions in which they made predictions concerning the amount of force applied in various situations, they commonly believed that large objects exerted more force on smaller objects and that smaller objects exerted less force on larger objects. This misconception is related to Newton's third law, that when forces occur in pairs where two objects interact they create equal amounts of force on each other, but in opposite directions. To address this misconception, Teacher D had students observe what actually occurs when two different sized carts bounce off each other in an elastic condition. He also had students explain in writing why the results occurred. In addition, Teacher D utilized computer Phet simulations to address this misconception. Students explained in writing whether these simulations changed the way they thought about Newton's third law and how their thinking changed.

Teacher D had his students, in a post assessment, make predictions about the amount of force that occurs in novel scenarios in which two objects collide and explain in writing the reasons for their predictions. He also analyzed the transcripts of two volunteer student interviews in order to glean student perceptions about which of the two interventions were most helpful to them and why. The post assessment predictions were much more likely to be accurate compared to those students made in the pre assessment. The analysis of student interviews indicated that both students preferred the computer Phet simulation to the cart demonstration. Teacher D plans to search for additional computer simulations to use in future lessons.

Teachers' perceptions of action research

According to teacher survey data, the four teachers described a plethora of benefits that resulted from their participation in action research. Foremost among them was that action research served as a way to ascertain if newly adopted interventions, such as those involving technology, would enhance student understanding of physics concepts. Three teachers cited an additional benefit was the gauging of students' perceptions about the effectiveness of the interventions. Another benefit entailed providing colleagues, administrators, and parents with information about the efficacy of new pedagogies. The following comments shared on the teacher survey, illustrate these benefits:

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> Whereas I often get a sense of what methods help the students the most, the action research gave me the opportunity to have a permanent record of their suggestions, making it more likely I'll incorporate them in future lessons.
>
> I find I'm much more confident in talking to my department colleagues about what I'm doing now that I have some actual data behind me.

Additional advantages of action research cited by at least one teacher included the potential to help students master state standards, the opportunity to know if they need to re-teach material, a heightened sense of professionalism, the motivation to refine new approaches, and enhanced teacher buy-in to a new pedagogy.

However, the teachers also shared several caveats including the lack of time to analyze the action research data and the perceived lack of expertise when it came to constructing journal prompts, survey items, and student interview questions. Other caveats included difficulty doing action research while also having a student teacher, lack of confidence with the writing process to report results, and difficulty understanding the impact of student absenteeism on the intervention. Two of the teachers remarked that an unexpected school-wide change in which teachers were required to use a standardized set of online activities and formative assessments affected the implementation of their intervention. The following comments from the teacher survey pertain to some of the aforementioned caveats:

> I found that the students absent the most, tended to perform poorly on the post assessments. It sort of then isn't a fair assessment as to how well the intervention worked. My next action research maybe needs to focus on how to help those who are often absent.
>
> It was difficult to master the new on-line materials and at the same time collect and review my action research data. I would suggest not trying to do action research when also implementing a new format of teaching.

Discussion and Conclusions

Although only four teachers participated in the present study, these findings hold some important implications for practice. First, the focus of each action research study provides novice teachers with a practical idea of common misconceptions possessed by ninth graders enrolled in an introductory physical science course as well as pedagogical innovations for addressing these misconceptions. All four of these interventions featured some use of technology ranging from slow motion videos to iPad applications to

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computer simulations in tandem with the opportunity for students to write about how their preconceived notions may have change. Cognitive neuroscience would argue that these approaches proved effective, in part, because of the attention-getting nature of technology as well as the opportunities to learn with peers. Both of these factors may serve to minimize anxiety and boredom, which can block the learning of new material because of the functioning of the amygdala, through which sensory data travel before moving to the prefrontal cortex for further processing (Willis, 2010). Another possible explanation for the efficacy of these interventions is that students must be in a state of cognitive disequilibrium when confronted by the unworkable nature of their own preconceived notions (Alparsian et al., 2004). In these four interventions, students were required to write about how their preconceived ideas may have changed over time. In two cases, the use of either slow motion video scenarios or computer simulations challenged students' misconceptions. In the other two cases, the experience of students working with their peers to create demonstrations or to reconcile the drawing of free body diagrams served to confront their preconceived ideas. Taken together, these explanations may provide a valuable means for understanding how to teach physics to ninth grade students, many of whom require concrete experiences to aid them in their processing of physics concepts (Adey & Shayer, 1990).

A second implication is that the descriptions of these projects may provide practical ideas as to how secondary physics teachers can conduct action research as well as associated difficulties and benefits. An analysis of the teacher-reported perceptions may suggest the need for both additional time and support for teachers conducting action research. The data also suggest the potential of action research to provide a means for sharing evidence as to the efficacy of new approaches with colleagues and parents and creating teacher ownership of new approaches, similar to findings reported in the literature (McNiff, 1996). Additionally, action research may promote the recording of student perceptions of new pedagogies and even their suggestions as to how to refine these for future use. Thirdly, the present investigation may contribute to an understanding of some of the practical factors affecting the process of doing action research in schools. Among the practical factors to emerge for these teachers were the following: how to determine the role of student absenteeism in understanding action research data, how to involve a student teacher in action research, and the dilemma of how to proceed with action research in a school milieu in which on-line standardization of the curriculum is pre-eminent. While undoubtedly the importance of these factors varies greatly by context, a consideration of some of the unanticipated realities of schools can illuminate the complexities teachers face as they conduct action research.

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