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THE IMPACT OF THE *MATERIALS EXPLORERS*™ CURRICULUM ON RELEVANCE AND ATTITUDES IN SCIENCE

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THE IMPACT OF THE *MATERIALS EXPLORERS™* CURRICULUM ON RELEVANCE AND ATTITUDES IN SCIENCE

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University of Pittsburgh, 2018

Students majoring in science, technology, engineering, and mathematics (STEM) are in high demand. Over 1 million STEM graduates will be needed by 2022 to meet the projected workforce needs (The Progress Report on Coordinating Federal Science, Technology, Engineering, and Mathematics Education, 2016). If students are needed to fulfill jobs in areas such as science and engineering, then high school science pedagogy needs to shift from being "unengaging" and "decontextualized" (Bøe, Henriksen, Lyons, & Schreiner, 2011, p. 58) to exciting and relevant.

Students in two sections of Honors Chemistry were evaluated using a series of self-report measures including: audience analyses of the planned and learned curriculum (Remillard, 1999) and a motivation and interest survey adapted from Keller's (2009) Course Interest Survey (CIS) and Instructional Materials Motivation Survey (IMMS). The purpose of these evaluations was to determine if the *Materials Explorers™* curriculum was relevant to students and the impact of relevant curriculum on students' attitudes towards science.

The results of this study indicated both *Materials Explorers™* activities led to increased value, satisfaction, interest, and connections to content. The *Materials Explorers™* Practical Prosthetics activity also led to increased content knowledge. A two-way ANOVA revealed significant differences in pre-test and post-test scores within both sections of Honors Chemistry

in regards to the Practical Prosthetics activity. There were not significant differences in pre-test and post-test scores for the Patterns of the Periodic Table activity. The results from this study are promising, however the sample size was small, and therefore the data is not generalizable. Additionally, many influences including initial differences between the treatment and control groups, teaching practices both groups were exposed to, and each group being aware of their status influenced the results.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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1.0 INTRODUCTION

My journey and coursework over the last three years of this program have led me to inquire about the development of curriculum and the ways the current curriculum I use in my science classroom motivates students. I am particularly interested in what motivates students to further pursue science and engineering curricula. I began to wonder if there was a connection between the relevance of science and engineering content and student's motivation and interest in pursuing a career in one of those fields. This curiosity of mine led me to a summer position at The Minerals, Metals, and Materials Society. The position provided the opportunity to collaborate with scientists, engineers, and educators from across the country to develop a science and engineering curriculum guide for high school students and teachers called *Materials Explorers*^{TM}. *Materials Explorers*^{TM} gave me the chance to create activities using best practices that would not only make content relevant to students, but also introduce students to career opportunities in science and engineering. This dissertation in practice is therefore a culmination of my experiences and inquiry as a teacher, researcher, and curriculum developer.

1.1 PROBLEM AREA

1.1.1 A call for engagement

The demand for science, technology, engineering and mathematics (STEM) experts continues to grow as the supply continues to diminish. Bottia, Sterns, Mickelson, Mollens, and Parker (2015) state "whereas other developed nations appear to be making rapid advances in preparing their youth in math, engineering, science and technology, U.S. children's interest in and academic preparation for STEM careers have not kept pace with projected societal needs" (p. 2). The Progress Report on Coordinating Federal Science, Technology, Engineering, and Mathematics Education (2016) states an additional 1 million STEM graduates will be needed by 2022 to meet the projected workforce needs and calls for the United States to engage all students in STEM.

While all students are being called to engage in STEM, there is a push to engage females, African Americans, and low-income students. These demographic groups are poorly represented in STEM fields yet they make up over two-thirds of college students (The Progress Report, 2016). More women are attending college, yet women remain the minority in math-intensive science, technology, engineering, and mathematics disciplines earning only 43% of degrees in mathematics and statistics, 19% of degrees in engineering, and 38% of degrees in the physical and technological sciences. Women are, however, well represented in medicine and health science, earning 59% of degrees (Wang & Degol, 2016). The call for engagement is targeted at all genders and age groups, ranging from elementary students to adults. The focus of this inquiry is high school students because the educational experiences students have in high school can reinforce interests in STEM (Maltese & Tai, 2010).

1.1.2 Motivation to pursue STEM

High school is a pivotal time in a young person's life. Many students enter high school with a wide variety of interests, many of which are not well formed. Over the course of four years, a student's high school experiences will determine her academic preparation, educational expectations, and career knowledge, all of which are essential to post-secondary success (Schneider, Judy, & Mazuca, 2012). Unfortunately, interest in school science tends to decline as students progress through school due to "transmissive pedagogy" and "unengaging, decontextualized content" (Bøe, Henriksen, Lyons, & Schreiner, 2011, p. 58). In other words, science curriculum does not appear to be motivating to students.

Motivation will be broadly defined as "what people desire, what they choose to do, and what they commit to do" (Keller, 2009, p. 3). The ARCS (Attention, Relevance, Confidence, Satisfaction) framework, developed by Keller (2009) is a motivational design framework based on expectancy-value theory, which suggests that behavior potential is a result of the strength of a person's expectations for success and the value they place on a desired goal. Motivational design focuses on making connections between instruction and a learner's goals, stimulating learners and providing appropriate challenges, and influencing learners' feelings after reaching or falling short of a goal (Keller, 2009).

The ARCS framework refers to attention, relevance, confidence, and satisfaction. The attention component of the framework focuses on piquing students' curiosities and interests. Relevance focuses on answering the ever popular question "why do I need to learn this?" by relating instruction to students' personal goals and helping them to feel connected with the classroom environment. The intent of the confidence component is to prove to learners that they can learn content and be successful when applying the content. Finally, satisfaction, which consists of intrinsic and extrinsic factors, strengthens students' desires to continue learning (Keller, 2009).

1.2 A PROBLEM OF PRACTICE

My problem of practice emerges from the larger issue of the STEM gap, with a particular focus on science and engineering. Over the course of my teaching career, I have realized that many of my students struggle to realize how the science they are learning in the classroom pertains to their everyday lives. This realization became apparent when I required students to journal once a week about the ways in which they had experienced chemistry over their weekend. I received many superficial answers such as "I made popcorn and the popcorn was a heterogeneous mixture because it had popped kernels and unpopped kernels." While I appreciated the students' attempts to connect chemistry to their life, I felt they did not see the relevance. Once I explained to a student the science behind popcorn and conducted an experiment where the students calculated the percent moisture in various brands of popcorn. The student became more motivated to learn about how percent composition related to other aspects of her life. This interaction caused me to reflect on the relevance of the content I was teaching.

My reflection began by analyzing the current curriculum, specifically how it was developed, who it was developed by, and the relevance to students' lives. During this reflection process, I discovered an opportunity to develop curricula for high school students through the Minerals, Metals, and Materials Society (TMS). Members from TMS were looking to create an outreach program called *Materials Explorers*^{TM}. The purpose of *Materials Explorers*^{TM} is to introduce high school students to relevant science and engineering curricula along with career pathways in those fields. *Materials Explorers*^{TM} afforded me the opportunity to consult with scientists, engineers, and educators from across the country to develop curricula for a set of topics predetermined by the *Materials Explorers*^{TM} committee.

Hernandez, Bodin, Elliott, Ibrahim, Rambo-Hernandez, Chen, and deMiranda (2014) discovered:

> Technology and engineering in STEM education are directly involved in problem solving, innovation, and design; three themes with high priorities on every nation's agenda. Given its economic importance to society, students should learn about engineering and technology within a STEM context and exercise the skills and abilities associated with the design process (p. 108).

The research conducted by Hernandez et al. makes it evident there is a need for students to learn about and pursue careers in science and engineering. One way to encourage this is to make STEM activities relevant by connecting them with societal needs. Hulleman and Harackiewicz (2009) further point out that when science courses are personally relevant in a meaningful way, students engage in the learning process, which may encourage them to identify with science careers, foster the development of their interest in science, and promote science-related academic choices and career paths.

Many of the *Materials Explorers*^{TM} activities reference comic book characters, mythologies, science fiction films, and other popular culture with the intent of engaging students in technical topics in a fun and compelling way. Popular culture in this study will therefore encompass music, movies, and television in this study. The rationale for selecting popular culture references was to tie instruction to learners' experiences. Keller (2009) argues that "in instruction, the use of concrete examples from settings familiar to the learner can help to achieve relevance, especially when teaching abstract material" (p. 50). Popular culture can also cause a "third space" model to emerge in the classroom where existing knowledge, identities, and power relationships are expanded upon and transformed (Lefstein & Snell, 2011). A third space model encourages students to acknowledge connections between their world and the curriculum they are learning. This model allows for exploration of one's identity, specifically, how cultural beliefs and practices intersect.

The ARCS framework allowed me to analyze my audience by assessing students' prior knowledge and experiences with science and engineering. Assessing prior knowledge and experiences helped me tie the designed curriculum or the goals and objectives based on standards (Remillard, 1999) to the learners' experiences and determine whether or not the *Materials Explorers*™ content is relevant to my students. Relevance in this study is operationally defined as meaningful ideas that fulfill the learners' goals (Means, Jonassen, & Dwyer, 1997). When science is made relevant to students' personal lives, even the most reluctant learners and students not interested in science view science as worth studying (Pickens & Eick, 2009). Once the activities are confirmed as being relevant to my students, the ARCS model will ensure that the enacted curriculum or a planned task turned into a classroom event, is aligned with the planned curriculum which lives in the mind of the teacher (Remillard, 1999). Finally, the ARCS model will allow me to survey students through a series of Likert scale questions about the enacted curriculum. The survey will provide insight on the learned curriculum and measure students' learning as well as their interest in the specific activity and attitude toward science.

2.0 LITERATURE REVIEW

A review of the literature afforded me the opportunity to narrow the scope of my inquiry. My inquiry began with a broad interest in understanding how experiences with high school curricula impact students' career interests. The review of literature allowed for exploration of the designed, planned, enacted, and learned curriculum (Remillard, 1999). The literature also allowed me to investigate motivation, specifically how content relevance motivates students to learn. Additionally, the literature revealed how interests are connected to careers. The questions below were derived from the broad scope of the inquiry and guided this review of literature:

1) What are the various phases of curriculum implementation? ***(2.1)***

2) What is the significance of relevant content when it comes to motivating students to learn science and engineering? ***(2.2)***

3) How is interest in science and engineering related to pursuing a career in those fields? ***(2.3)***

The literature review explores the connections between high school experiences with curriculum, motivation to learn science and engineering, and interest in pursuing science or engineering as a career at an in-depth level. The connections between the inquiry questions that drive the literature review contribute to the current literature on the STEM gap.

2.1 PHASES OF CURRICULUM IMPLEMENTATION

The push to create a relevant high school science curriculum is not a novel idea. The National Science Education Standards state "schools that implement the Standards will have students learning science by actively engaging in inquiries of interest and importance to them. Such students will establish a knowledge base for understanding science" (National Research Council, 1994, p. I-5).

Curriculum can be viewed through the following four perspectives: designed, planned, enacted, and learned (Remillard, 1999). In this study, curriculum will be defined as "a plan for the experiences that learners will encounter, as well as the actual experiences they do encounter" (Remillard & Heck, 2014, p. 707). The designed curriculum refers to the goals and objectives described by textbooks and standards whereas the planned curriculum refers to the teacher's plans for implementing the curriculum. The curriculum is then enacted by educators who decide on the content, pedagogy, and assessments that will be implemented. Students, the beneficiaries of the teachers' actions, experience the curriculum, ideally achieving intended learning outcomes (Matthews, Adams, & Goos, 2016). It is important to note that curriculum does not merely refer to textbooks, but is all encompassing and includes "pedagogical guidance and an outline of the development of the content" (Remillard, Harris, Agodini, 2014, p. 735). Finally, the learned curriculum refers to the impact the enacted curriculum had on student learning (Remillard, 1999).

2.1.1 Designed and planned curriculum

The designed curriculum refers to the goals and objectives described by various resources, such as textbooks. A main goal of science education is to encourage students to reason scientifically (AAAS, 1993). Students are also encouraged to learn science by "doing science" instead of "reading about science" according to Tekkumuru, Stein, and Schunn (2015). The designed curriculum is also informed by curricular aims and objectives and is created for the teacher as its primary audience (Remillard & Heck, 2014). The designed curriculum becomes the planned curriculum as the teacher elects which tasks to implement, when to implement them, and how to implement them. Remillard (1999) notes:

> A crucial component of a teacher's role in curriculum development is the process of selecting, altering, and constructing tasks to present to students. The tasks that a teacher selects, regardless of the extent to which they differ from those described in the textbook, represent the teacher's assumptions about content (what students should learn) and pedagogy (how they should learn it) (p. 323).

Remillard also explains there are two approaches to task selection: appropriation and invention. The appropriation of a task occurs when a teacher selects a task from a textbook or other curriculum guide, assuming the task embodies current practices. Invention is when the teacher utilizes the textbook or curriculum guide for inspiration on a topic and develops her own task. Both approaches to task selection provide insight into the planned curriculum, specifically how the teacher plans to "use" the textbook or curriculum guide.

The planned curriculum is challenging to study because it primarily lives in the mind of the teacher (Remillard & Heck, 2014). Lesson plans can be used as an artifact of the teacher's plans, however, they often fail to capture all facets of the lesson plan as imagined by the teacher. In this study, the designed and planned curriculum will not only be informed through standards and objectives, but through a formative assessment Keller (2009) refers to as an audience analysis. The audience analysis allows the teacher to collect data on students' prior knowledge and experiences and generate a learner motivational profile for the class (Keller, 2009). This data will inform the planned curriculum, causing the teacher to explicitly identify the steps she will take while enacting the curriculum. Knowing ahead of time the experiences and prior knowledge students are bringing to the table will allow the teacher to develop a more thorough lesson plan.

2.1.2 Enacted curriculum

The enacted curriculum is when teachers and students transform planned tasks into classroom events (Remillard, 1999). A classroom event or lesson is comprised of "all interactions in the classroom, planned or unplanned, that influence, shape, or contribute to the enacted curriculum" (Remillard, p. 328). During a lesson the task may need to be adapted or adjusted according to students' needs, thus the enacted curriculum can differ from the planned curriculum. Stein, Grover, and Henningsen (1996) identify factors that can influence the enacted curriculum and need for task adaptation such as classroom norms, task conditions, and teachers' and students' habits and dispositions. The enacted curriculum is focused on instructional tasks, because working on tasks is what students *do* during the majority of the lesson (Boston & Smith, 2009). Gehrke, Knapp, and Sirotnik (1992) caution that the enacted curriculum in various content areas, including science, is not what scholars agree should be taught. Science curriculum tends to "focus on factual knowledge rather than conceptual understanding" (p. 89) albeit the vision for science as identified by the American Association for the Advancement of Science in Project

2061 includes unifying ideas that extend from elementary through secondary, interdisciplinary thinking, connections between science and technology and science and society, scientific “habits of mind”, and inquiry skills (Gehrke et al., 1992). The enacted curriculum is not the only aspect of curriculum where science is flawed. There is a considerable disconnect between the planned and enacted curriculum and an even further disconnect between the planned curriculum and the learned curriculum. The disconnect stems from the planned science curriculum consisting primarily of lectures and demonstrations; methods of instruction which are most effective for students pursuing a career in science or engineering (Gehrke et al., 1992).

The difference between the planned and enacted curriculum is shaped by the day-to-day decisions teachers are forced to make when preparing and delivering lessons. The enacted curriculum in one classroom is likely to be drastically different from the enacted curriculum in the class next door, even though the content may be the same. These differences in the enacted curriculum are due to “teachers’ beliefs, knowledge, preferences, and responses to the constraints and opportunities of particular classroom settings” (Gehrke et al., 1992, p. 100). The enacted curriculum has the greatest impact on student outcomes (Remillard & Heck, 2014). It is therefore imperative that the dimensions of the enacted curriculum are reliably measured.

Classrooms are dynamic and complex, thus there are many components of interest, albeit these components can be challenging to define and difficult to measure (Remillard & Heck, 2014). Prominent features of enacted science curriculum include content, instructional interactions, pedagogical moves, and the use of resources and tools. The scope of this study is too small to focus on all aspects on the enacted curriculum, thus the observation protocol which will be completed by an outside observer will focus on the content and specific pedagogical moves identified by Keller (2009) as motivational tactics. Examples of motivational tactics include relating instruction to learners' goals, linking instruction to personal interests of the learners, and tying instruction to learners' experiences (Keller, 2009). Science content includes specific content ideas as well as how they are represented and engaged while pedagogical moves refer to a teacher's intentional and unintentional actions that shape the representation and investigation of the science content being taught (Remillard & Heck, 2014).

2.1.3 Learned Curriculum

Student outcomes are most often the variable of interest in curriculum studies. Outcomes are a result of the enacted curriculum and can include the acquisition of skills, understandings, and strategies (Remillard & Heck, 2014). The outcome of interest in this study is students' attitudes towards science and engineering and will be discussed later in this chapter. The authors describe the relationship between outcomes and the enacted curriculum as bidirectional because "students learn through their interactions with the tasks, the materials, each other, and the teacher, they contribute to ongoing construction of the enacted curriculum" (Remillard & Heck, 2014, p. 713). While student outcomes are often what is explicitly learned from the enacted curriculum, there are also implicit products of the enacted curriculum known as the "hidden curriculum" (Remillard & Heck, 2014, p. 713). The "hidden curriculum" conveys to the learner how they should participate in class and what it means to know the content being taught.

2.2 MAKING CONTENT RELEVANT

Student motivation is the most important factor in raising curriculum standards (Fairbrother, 2000) therefore it is critical that instructional designers understand the principles of motivation and how they apply to instruction. Means, Jonassen, and Dwyer (1997) argue "the only coherent and comprehensive instructional design model accommodating motivation is the ARCS (attention, relevance, confidence, and satisfaction) Motivational Model" (p. 5). The authors also note motivation theory argues that "relevant phenomena better fulfill personal needs or goals, thus enhancing effort and subsequently performance" (p. 6). Thus, the relevance component of the ARCS Motivational Model will be used as the framework for this study to measure the enacted and learned curriculum. The ARCS model argues that relevance-enhancing strategies to improve motivation and performance should be embedded in instruction to connect the learning to the learner (Keller, 2009).

The question "what makes the learning in school relevant to the students' life and their future?" (p. 3) has been plaguing educators since the start of the twentieth century (Stuckey, Hofstein, Malmok-Naaman, & Eilks, 2013). Keller (1983) defined relevance as instruction that satisfies students' personal and career goals. This means that educators must be aware of students' career aspirations and understand what they consider useful, meaningful, and important. The definition of relevance in this study will be synonymous with Keller's definition.

Holbrook and Rannikmäe (2007) suggest that relevant learning in science classes occurs when a constructivist approach is taken that allows students to connect new knowledge to a familiar setting or meaningful context. Kotkas, Holbrook, and Rannikmäe (2016) note:

> When developing learning materials, educators tend to pursue their own perception of relevance rather than the perception of what may be considered relevant to

> the student. This, in turn, can reduce the students' perception of intrinsic relevance, which in turn can impact on students' motivation to learn science (p. 196).

This study will attempt to minimize the teacher's perception of relevance from biasing the planned and enacted curriculum by conducting an audience analysis (Keller, 2009) which provides information such as students' prior knowledge and experiences as they pertain to the content.

A study conducted by Shellnut, Knowlton, and Savage (1999) supports the relevance component of Keller's ARCS model in computer-based instruction. In this study, the authors proposed the question "what can be done to make each module relevant to the learner's present experiences or future expectations" (p. 105). This question is one still frequently posed today in classrooms and can be addressed through general techniques of increasing relevance such as analyzing the audience and providing choice for the learner so she can select methods that most closely identify with her experiences (Shellnut, Knowlton, & Savage, 1999). Additionally, results from the study led the researchers to include professionals as well as educators in the process of designing the curriculum, since their repertoire of relevant activities differed. This idea of combining professionals and academics to design curriculum parallels a goal of the *Materials Explorers*^{TM} program.

2.3 FACTORS AFFECTING INTEREST IN SCIENCE

Studies conducted by Hulleman and Harakiewicz (2009) and Gaspard et al. (2015) show that students perform better and are more interested in a subject when they make a connection between their lives and the content they are learning at school. Keller's ARCS model is rooted in

Vroom's expectancy-value theory (Keller, 1983; Small, 1997; Vroom, 1964) which provides suggestions for curriculum intervention including providing a curriculum that students value and raising students' expectancy levels by ensuring that all students experience successful learning. Vroom's expectancy-value theory is based on three facets: valence, instrumentality, and expectancy (Van Eerde & Thierry, 1996). Valence is defined as "the importance, attractiveness, desirability, or anticipated satisfaction with outcomes" (Van Eerde & Thierry, 1996, p. 576). Instrumentality refers to the probability of obtaining an outcome and expectancy is the correlation between an action and an outcome (Van Eerde & Thierry, 1996). This theory allows teachers to develop learning environments that foster and maintain motivation, even though the enacted curriculum is not completely in their control (Feng & Tuan, 2005).

2.3.1 Interest-enjoyment Value

Interest-enjoyment value refers to how interested individuals are in the subject in question and the enjoyment they feel when participating in it (Bøe, Henriksen, Lyons, & Schreiner, 2011). According to the Future Track survey, a large-scale longitudinal survey that followed students from applying to college until they found their first job, interest in, and enjoyment of the subject were among the most frequently stated reasons for educational choice (Purcell, Elias, Ellison, Atfield, Adam, & Livanos, 2008). Interest in a topic however can differ from interest in a topic as experienced in school. Developing interest in school science in young adults is challenging. School science pedagogy has a stereotype, and often lives up to it, of being transmissive, unengaging, and difficult (Bøe, et al., 2011). School science needs to be redesigned to be relevant and interesting. Barmby, Kind, and Jones (2008) found that in order to generate interest in pursuing science, school science needs to be enjoyable for students.

Haussler and Hoffmann (2000) discovered that a “curriculum which lets the students engage in activities in which they are interested and which presents content in the context of situations meaningful to them is superior to the traditional curriculum” (p. 704). The authors also noted that interest in a topic as experienced in school is often linked to achievement and found that students’ interest in physics was not really due to being interested in the content, but connected to the students’ self-esteem as being good achievers. Haussler and Hoffmann (2000) found that students who engaged in curriculum that was relevant and interesting to them were more successful in retaining content knowledge. This aligns with the idea proposed by Eccles and Wigfield (2002) that interest and achievement are positively related.

2.3.2 Attitudes Towards Science

Over thirty years of research has been dedicated towards understanding “attitudes towards science.” The difficulty with understanding what is meant by “attitudes towards science” arises because attitude is not a single construct. It is composed of several sub-constructs, all of which contribute, with varying weights, towards one’s attitude (Osborne, Simon, & Collins, 2003). According to Osborne, Simon, & Collins (2003, p. 1054), the following sub-constructs that contribute to an attitude towards science are:

- The perception of the science teacher;
- Anxiety toward science;
- The value of science;
- Self-esteem at science;
- Motivation towards science;
- Enjoyment of science;

- Attitudes of peers and friends towards science;
- Attitudes of parents towards science;
- The nature of the classroom environment;
- Achievement in science; and
- Fear of failure in course.

As previously noted, the scope of this study is small; therefore it is not feasible to study all of the sub-constructs that compose attitudes towards science. This study will focus on the value of science, motivation towards science, enjoyment of science, and achievement in science. These sub-constructs will become the operational definition for science attitude. It should also be noted that because this study will be conducted in a school setting, the resulting attitudes towards science are a reflection of attitudes towards school science in one high school setting.

2.4 CONCLUSION

The review of the literature afforded me the opportunity to explore how curriculum relates to students' interest in science and engineering. Through my review of the literature I discovered that the designed and planned curriculum usually differ from the enacted curriculum which is even further removed from the learned curriculum (Gehrke, Knapp, & Sirotnik, 1992). This discovery helps rationalize the structure of this study, which evaluates the planned, enacted, and learned curriculum separately. These individual measures will allow for triangulation of the data and increase the rigor of the study as well.

The literature review also uncovered that relevant instruction is not only related to student motivation, but also to interest and achievement (Gaspard et al., 2015; Hulleman &

Harakiewicz, 2009). The concept of relevance as central to the learned curriculum supports the decision to focus solely on relevant instruction as opposed to all facets of the ARCS Motivational Model. Finally, investigating the relationship between the enacted and the learned curriculum will allow me to understand how relevant instruction affects attitudes towards science (Osborne, Simone, & Collins, 2003).

3.0 STUDY APPROACH AND METHODS

3.1 INQUIRY QUESTIONS

The principle goal of this study was to understand how experiences with high school science and engineering curricula impact students' career interests in those fields. This overarching goal was narrowed into a study consisting of investigating the relevance of science and engineering curricula and exploring a relationship between curricula and career interests. This study was further broken down into three inquiries, using the *Materials Explorers*^{TM} curricula. The *Materials Explorers*^{TM} curricula was designed with the purpose of exposing students to real-world applications of science and engineering as well as career opportunities in those fields, albeit the designed curriculum may differ from the planned, enacted and learned curriculum.

The first inquiry was as follows:

1) What did students learn regarding the following topics:

i. *patterns of the periodic table*

ii. *biomaterials*

I first analyzed my audience by completing a learner analysis (Keller, 2009). The audience analysis (Appendices A and C) consisted of investigating the knowledge students had regarding periodic table patterns and biomaterials. The audience analysis consisted of multiple choice and short answer questions that were related to both content and personal experiences.

The learner analysis was conducted prior to engaging in the activities, allowing the results to influence the planned instruction. The same questions posed in the audience analysis were also asked of the students after enactment of the curriculum. The data collected through both learner analyses was compared to determine if students' interests and attitudes towards the content changed, and if so, in what ways.

I then investigated the connection between motivation and interest, leading to my second inquiry:

2) *In what ways are the enacted Materials Explorers ™ activities relevant to students?*

The motivational delivery checklist (Keller, 2009) was used as an observation tool to ensure students understood the relevance of the topic they were engaging in. The motivational delivery checklist required an outside observer, in this case the assistant principal, to observe the methods the classroom teacher used to highlight connections between content and careers and incorporating learners' experiences, interests, and goals into problems posed. A study conducted by Kember, Ho, and Hong (2008) noted that students are motivated to learn about a topic when the teacher makes the information relevant to their lives. Kember et al. also note that relevance is established by using real-life examples, drawing cases from current issues, giving local examples, and relating theory to practice.

The link between relevance and interest led to my final inquiry:

3) *How do relevant activities affect students' attitudes toward science?*

A study conducted by Feng and Tuan (2005) found that if students value chemistry, understand how it can be used in daily life, and believe chemistry stimulates their thinking, then they are more motivated to learn science. Students' interest in patterns of the periodic table and biomaterials were gauged through an adapted version of Keller's (2009) course interest survey and additional open-ended questions constructed by the researcher.

The three inquiries described above allowed me to break the principle goal of this study into the following manageable parts: uncovering students' prior knowledge and experiences with patterns of the periodic table and biomaterials, the relevance of the enacted *Materials Explorers*™ activities, and the relationship between relevance and attitudes towards science.

3.2 INQUIRY APPROACH

The inquiry approach for this study was action research since it was conducted within my classroom. The framework that guided this inquiry was the ARCS model developed by Keller (2009). The ARCS model stands for attention, relevance, confidence, and satisfaction and has been validated through studies by Wlodkowski (1999) and Shellnut, Knowlton, and Savage (1999). Keller (2009) notes that motivational interventions do not have to extend across all four categories, but can be focused within one of the categories. Therefore, this study focused on relevance as opposed to the entire ARCS model.

3.2.1 School and district setting

Franklin Regional High School, which has an enrollment of 1,223 students (USA News and World Report, 2018), is part of a suburban, public school district located east of Pittsburgh, Pennsylvania in the municipality of Murrysville. In addition to Murrysville, the district boundaries also include the boroughs of Delmont and Export. The Franklin Regional School

District is a close-knit community whose residents, according to the American Community Survey (2016), predominantly (99.1%) identify as White. The majority of residents in the school district (94.3%) earned a high school diploma while 25.4% of its residents earned Bachelor degrees or higher. 20.4% of the Murrysville and Delmont populations as well as 25.6% of the Export population classified their occupation as being part of: manufacturing or professional, scientific & management, and administrative & waste management services industries (American Community Survey, 2016).

3.2.2 Participant Selection

The *Materials Explorers*™ activities were assigned to one of the two sections of Honors Chemistry that I taught at Franklin Regional High School during the 2017-2018 school year. Honors Chemistry, a science elective, is a first-year chemistry course offered to any student in grades ten through twelve. The class sections were not randomly assigned to the treatments, therefore this study is a quasi-experimental study that compares two inequivalent groups. Table 1 below highlights the demographics of each group:

Table 1. Demographics of the treatment and control groups

Demographic	Honors Chemistry Period 5 Control Group	Honors Chemistry Period 7 Treatment Group
Number of students enrolled in course	27	28
Number of students who participated on surveys	22	24
Gender	10 males, 17 females	13 females, 15 males
Grade level	13 sophomores, 14 juniors	19 sophomores, 9 juniors
Ability	4 students identified as gifted	8 students identified as gifted, 1 student identified as needing special education services
Experience	2 students have no experience with honors courses	All students have experience with honors courses
Technology Access	1 student did not have access to a cell phone or home computer	All students had access to cell phones and home computers

Both sections of Honors Chemistry are comparable in size, yet heterogeneous by gender, grade level, and ability. The ratio of males to females in the control group was higher than the treatment group. Over half of the male students in the control group were juniors which is why the control group consisted of more juniors than sophomores while the treatment group was composed of several more sophomores than juniors. Additionally, twice as many students in the treatment group were identified as gifted compared to those in the control group and all students in the treatment group had previously and/or were concurrently enrolled in at least one Honors course.

Students enroll in Honors Chemistry for a variety of reasons, according to surveys issued on the first day of the course, including: weighted grades, genuine interest in science, the desire for a challenge, college requirements, or disinterest in other science electives offered. Since Honors Chemistry is designed for students interested in pursuing science majors, I felt the tools used including the course interest survey questions as part of the audience analysis would yield more valuable findings from this segment of the school population.

The rationale for selecting period seven as the treatment group was two-fold. All students had access to technology outside of the classroom therefore, I knew they would easily be able to complete assignments for homework. I also wanted to test a claim set forth by Haussler and Hoffmann (2000) which stated that students were more likely to retain content knowledge when they engaged in curriculum they perceived as relevant and interesting. I wanted to see if this claim held true for students in period seven since on paper the class consisted of more students identified as gifted as well as younger students compared to period five, indicating more students in period seven were on an advanced science pathway.

3.2.3 Designed and Planned Curriculum

The first step of my inquiry approach was to analyze my audience to determine students' prior knowledge of patterns of the periodic table and biomaterials. The rationale for inquiring about students' knowledge in the two content areas mentioned above is because tasks regarding those topics composed the enacted curriculum. Patterns of the periodic table is a required curriculum topic for Honors Chemistry. Biomaterials is not directly a required curriculum topic for Honors Chemistry. However, the lens of biomaterials was used to teach about states of matter, which is a required topic. The tasks for the students in the treatment class were reviewed by a panel of six high school educators from across the country as well as a group of scientists and engineers who were members of The Minerals, Metals, and Materials Society. The reviewers were directed to evaluate the activities for technical accuracy, ease of implementation in the classroom, the level at which they felt students would be engaged, relevance of the activities to careers in STEM, and the alignment of the activity to the Next Generation Science Standards (NGSS). The educators reviewed the tasks upon initial development while the scientists and engineers reviewed the tasks upon initial development and prior to publication. It should be noted that the activities used in this study were in draft form and the final publication of the *Materials Explorers*™ activities will occur after this study has been conducted so that feedback, as a result of this study, can be incorporated.

The periodic table task utilized by the students in the treatment group required the students to create a superhero persona inspired by an element on the periodic table. Students were required to describe strengths, weaknesses, and powers of the superhero in terms of the physical and chemical properties of the element that inspired it. Additionally, students in the treatment group completed an extension activity that helped them make connections between the science behind superheroes and the real world. The control group Patterns of the Periodic Table activity was developed and reviewed by the Franklin Regional High School Chemistry professional learning community (PLC) team. Students in the control group selected an element from the periodic table and completed a web quest. The web quest required students to research the following information about their element: basic information, a poem from the periodic table of poetry, a haiku, a science fiction story, and a comic. The final task of the activity was for students to design their own haiku, song, or cartoon featuring their element and incorporating the basic information they discovered.

The Practical Prosthetics activity used by the control group was nearly identical to the task used by the treatment group. Therefore, both groups engaged in the *Materials Explorers™* version of the activity. The only difference between the activities was that the treatment group's activity related to popular culture by repeatedly referencing and making connections to the television show *Grey's Anatomy* while the control group's activity did not reference or make connections to the show. The activity the control group participated in was nearly identical to the *Materials Explorers*^{TM} activity the treatment group engaged in because no comparable activity had previously been created by the Franklin Regional High School Chemistry PLC since biomaterials was not directly part of the required curriculum. The Practical Prosthetics activity tasked students to create a viscoelastic material and calculate the amount of stress and strain the material could endure. Students were then required to write an evidence based conclusion determining if the viscoelastic material they created should be used in prosthetics. Both groups also participated in an extension activity where students read an article about biomaterials and bio absorption. After reading the article, both groups answered questions that required them to make connections between biomaterials and bioengineering.

Analyzing the audience is an essential step in determining the motivational strategies that should be used in the activity (Suzuki & Keller, 1996). Motivational strategies include introducing popular culture references, case studies, and experiential activities. Analyzing the audience consisted of assessing prior content knowledge through multiple-choice questions that were developed by the chemistry PLC from the Franklin Regional School District, a public school district in Pennsylvania. The questions created by the PLC have been tested and adapted in Franklin Regional Senior High School classrooms based on data collected over the past seven years. In addition to content knowledge questions, Likert-scale questions from Keller's (2009) course interest survey that pertain to relevance were adapted by the researcher to open-ended questions. The Likert-scale questions for the audience analysis included *NO! no! yes! YES!* The rationale for adapting the Likert-scale questions comes from Gardner (1975) who explains:

> An attitude instrument yields a score. If this score is to be meaningful, it should faithfully reflect the respondent's position on some well-defined continuum. For this to happen, the items within the scale must all be related to a single attitude object. A disparate collection of items, reflecting attitudes towards a wide variety of attitude objects, does not constitute a scale, and cannot yield a meaningful score (p. 12).

The results from the audience analysis were used to inform the planned curriculum.

3.2.4 Enacted Curriculum

The planned curriculum was then enacted in the classroom setting. The planned curriculum, patterns of the periodic table and biomaterials activities, were implemented through assignment according to the table below:

Table 2. Assignment of the planned curriculum to the various sections of Honors Chemistry

Chemistry Section	Task 1: Patterns of the Periodic Table	Task 2: Biomaterials
Honors Chemistry Period 5	Control	Control
Honors Chemistry Period 7	Treatment	Treatment

Note. Students in the treatment group completed the *Materials Explorers*^{TM} version of the activities

During the implementation of the planned curriculum, the assistant principal acted as an observer. He observed the enacted curriculum in the treatment and control classrooms and used the observation protocol (Appendix C) to ensure the enacted curriculum was implemented with fidelity and contained motivational strategies that made the content relevant.

The treatment group participated in two *Materials Explorers*^{TM} activities: Powers of the Periodic Table (Appendix H) and Practical Prosthetics (Appendix K).

Powers of the Periodic Table encouraged students in the treatment classroom to compare theoretical superpowers to real-world scientific applications that make them possible. The activity also required students to use their knowledge of a selected element to synthesize a superhero, explain the arrangement of the periodic table, and research the role of materials science and engineering in simplifying modern life. Finally, students had to discuss the relationship between valence electrons and reactivity and the importance of reactivity in materials science. Practical Prosthetics required students in the treatment classroom to describe the properties of viscoelastic materials, compare solids and liquids, define polymers and identify examples of polymers, and define biomaterials, identify applications, and relate viscoelastic materials to prosthetics.

Students in the control classroom completed an element project, which required students to research real-life uses of elements, the arrangement of the periodic table, the ways elements have simplified modern life, and the connection between the number of valence electrons and reactivity. Additionally, students created a poem, song, or comic strip, based on their interest, synthesizing the information they researched. In the control classroom, students compared solids and liquids, describe the properties of viscoelastic materials, and defined and identified examples of polymers.

After the observer documented the enacted curriculum in both the control and treatment classrooms, students answered the same questions posed during the audience analysis which consisted of content knowledge questions created by the Franklin Regional School District chemistry PLC which had been previously piloted over seven years as well as adapted questions from Keller’s (2009) course interest survey that pertain to relevance (see Appendix B).

The purpose of having students engage in the audience analysis and answer the same questions after engaging in the activity was to determine the impact the activities had on the learner motivation profile of the class and their interest. Finally, students completed an interest and motivation survey adapted from Keller's (2009) Course Interest Survey and Instructional Materials Motivation Survey (Appendix E) to determine the effect the activity had on their attitudes towards science. The Likert-scale questions for the interest and motivation survey included *Not true*, *Slightly true*, *Mostly true*, and *Very true*. The data collected from the audience analysis, observation, post-activity audience analysis, and interest and motivation survey were triangulated through a process explained later in this chapter.

3.3 METHOD OF ANALYSIS

3.3.1 Overview

The ARCS model of motivation, which stands for attention, relevance, confidence, and satisfaction was developed by John Keller. The ARCS model is applicable in a variety of settings including the public and private sectors and was intended for use by those involved in designing or delivering instruction (Keller, 2009). Motivation is complex. There are a plethora of concepts, constructs, and theories pertaining to motivation due to the complexity of environmental, cultural, and personal factors that interact to influence a person's motivation at any point in time (Keller, 2009). A problem with motivation is measuring the elements that make up motivation such as human characteristics, design strategies intended to influence motivation, social and environmental conditions, and consequences (Keller, 2009). This study therefore focused solely on the relevance aspect of Keller's ARCS model which includes solely measuring the design strategies intended to influence motivation.

There is a lack of interest in science learning and students are not motivated by science subjects, often because science is perceived as irrelevant to individuals and the society in which those individuals live (Stuckey et al., 2013). To counteract this perception, science teachers need to make science relevant in order to motivate students and pique their interest in science (Stuckey et al., 2013). Keller (2009) supports the idea that relevance determines a students' motivation to learn and explains that during instruction, the use of concrete examples that relate to settings familiar to and interests of the learner can help achieve relevance, particularly when content being delivered is abstract. This idea is particularly important when addressing the first two inquiry questions, which focus on students' prior knowledge and the relevance of the *Materials Explorers*™ activities to students' lives.

3.3.2 Analyzing the Audience

Analyzing the audience allowed me to generate a motivational profile of the class and determine the types of motivational situations that exist within each class such as a student whose initial motivation is too high or too low. According to Keller (2009), if a student's motivational level is too low, his achievement will be low due to little desire to succeed leading to minimal effort. On the contrary, if a student's motivational level is too high, the quality of his performance will decrease due to stress leading to an inability to recall information (Keller, 2009). It should be noted that a student's true motivational level could not be known, only his or her expressed motivational level can be measured (Osborne, Simone, & Collins, 2003). The typical motivation profile for a class resembles *Figure 1* below, where the majority of students fall in an acceptable range of motivation, leading to high performance.

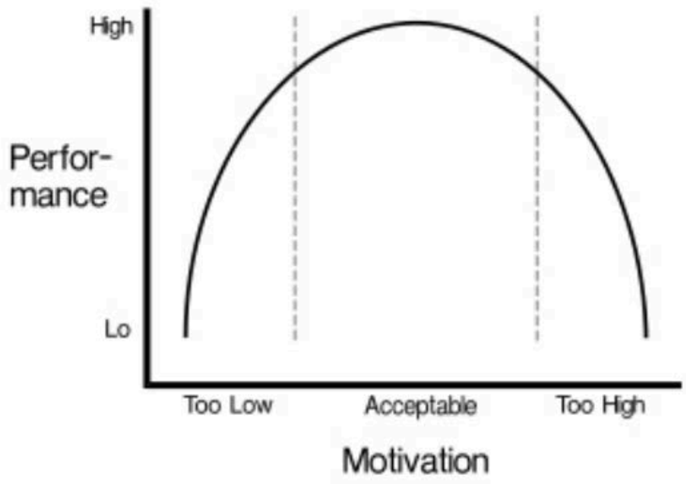


Figure 1. Curvilinear dynamics of learner motivation (Keller, 2009)

A strength of the learner motivation profile is that all facets of the ARCS model are taken into account. The audience analysis revealed the attention readiness of the learners or "the degree to which the audience will be likely to respond with curiosity and attention to the instructional material" (Keller, 2009, p. 213). The perceived relevance (e.g., whether or not the audience believes the instruction will meet its personal goals) also was revealed. Confidence and satisfaction were also evaluated through the learner analysis.

The audience analysis (Appendix A) was conducted prior to students engaging in either of the *Materials Explorers*™ activities and consisted of content-based questions that were piloted by students for the past seven years and designed by the Franklin Regional High School Chemistry PLC. Questions addressing each facet of the ARCS model were also posed during the audience analysis. The rationale behind asking both content related and motivation related questions was to determine students' prior knowledge of the content, addressing the first inquiry question. An audience analysis (Appendix B) was also conducted post instruction to determine how the learner motivation profile changed.

The content related questions on the audience analysis were graded using the answer key developed by the chemistry PLC. Prior to coding data, all written student responses were typed into a document, leaving a large margin for notes and codes. The document was printed out so annotations could be recorded in the margins. The responses to the Likert scale questions were manually coded through the lenses of the four research areas identified in the observation protocol: goal orientation, motive matching, familiarity, and relevance. The responses to the audience analyses were coded a second time to reveal patterns in the data. Recoding with a narrower perspective will allow patterns to develop and even allow for additional categories to emerge (Saldana, 2009). Any emergent codes were recorded in a separate codebook including the code, description, and data example (Saldana, 2009).

3.3.3 Observation Protocol

Keller (2009) designed and revised, over a number of years, a motivational tactics checklist with the intention of analyzing "print types" of material. Additionally, Keller and colleague Armstrong also designed a motivational delivery checklist for analysis of instructor-led classes. The statements on the motivational tactics checklist and motivational delivery checklist were adapted by the researcher to open-ended, observable questions and combined to create the observation protocol (Appendix C) used in this study. Keller's motivational tactics checklist and motivational delivery checklist both include all components of the ARCS model, however the observation protocol for this study focused the observer on the relevance component which was broken down into three research areas: goal orientation, motive matching, and familiarity. The observation protocol allowed for the enacted curriculum to be evaluated and the first two inquiry questions to be addressed. The data collected during the enactment of the lesson was used as evidence to answer questions in each of the three research areas mentioned above. The raw observation data and the responses to the questions after the lesson were coded using the method described in the previous section.

3.3.4 Interest and Motivation Survey

The adapted interest and motivation survey containing questions from the relevance sections of the course interest survey (CIS) and the instructional materials motivation survey (IMMS) (Appendix D) addressed the third inquiry question by assessing students' situation-specific attitudes. The CIS and IMMS can be used in their entirety, which consists of all four components of the ARCS model, or the four subscales can be used and scored independently (Keller, 2009). The surveys were validated through several studies such as Small and Gluck (1994) and Hu (2008). In this study, primarily the relevance subscales were used and adapted by the researcher to reference the specific activity.

3.3.5 Triangulation Matrix

Once all data was collected and coded according to the four research areas, the codes were entered into the triangulation matrix table below:

Table 3. Triangulation matrix of methods

		Designed and Planned Curriculum	Enacted Curriculum	Learned Curriculum	Learned Curriculum
Inquiry Question	Research Area	Audience Analysis	Observation Protocol	Audience Analysis	Interest and Motivation Survey
1	Familiarity	X	X	X	
2	Motive Matching		X		X
3	Goal Orientation	X		X	X

The triangulation matrix increased the rigor of the methods by verifying that multiple measures were used during each step in the curriculum process. The data collected through each step in the curriculum process directly addressed the following three inquiry questions:

1) *What did students learn regarding the following topics:*
    i. *periodic table patterns*
    ii. *biomaterials*
2) *In what ways are the enacted Materials Explorers ^{TM} activities relevant to students?*
3) *How do relevant activities impact students' attitudes toward science?*

Once all data was coded using the methods described in the previous sections, the data was sorted based on the triangulation matrix to reveal connections between the inquiry questions and the designed and planned, enacted, and learned curriculum.

4.0 SUMMARY OF FINDINGS

Over the course of my teaching career, I have personally witnessed many students struggle to make connections between the science they are learning in the classroom and their everyday lives. Students often express their frustrations saying "why do we have to learn this?" I have realized that when I make content relevant to the students' lives they are not only less frustrated, but are enthusiastic about learning and take pride in making connections. The purpose of this study was to investigate the relationship between relevant content and students' attitudes towards science. To address this relationship, I provided different instruction to two different sections of Honors Chemistry. One section of Honors Chemistry, the treatment group, participated in the *Materials Explorers*^{TM} activities while the second section of Honors Chemistry, the control group, participated in traditional activities that were developed by the Franklin Regional High School Chemistry professional learning community (PLC).

The findings of this study will be addressed according to the research questions. The first section is divided into two parts: part one refers to the results from the patterns of the periodic table activity and part two refers to the results from the biomaterials activity. The first section examines the question: *1) What did students learn regarding patterns of the periodic table and biomaterials?* Evidence for the first research question was collected via audience analyses of the learned curriculum and through observation of the enacted curriculum. The second section examines the question: *2) In what ways are the enacted Materials Explorers* ^{TM}

activities relevant to students? The second question approached relevance in terms of connecting to students' everyday lives through popular culture references. Data for the second collection was collected through the observation protocol and the interest and motivation survey.

Finally, the last section examines the question: *3) How do relevant activities impact students' attitudes toward science?* The final question explores the influences of popular culture on students' perspectives of science. The final question also draws connections between popular culture influences and students' interests in pursuing careers in science. Data for the final question was gathered from the audience analyses of the planned and learned curriculums as well as the interest and motivation survey.

4.1 KNOWLEDGE OF PATTERNS OF THE PERIODIC TABLE

According to Fairbrother (2000), student motivation is the most important factor in raising curriculum standards. If student motivation is a critical factor in raising curriculum standards, then it is essential to develop a motivational profile of the class so the curriculum can be designed to motivate and inspire students. Before a motivational profile could be developed, students' knowledge of patterns of the periodic table and biomaterials had to be assessed through an audience analysis. The audience analysis helped address *question 1: What did students learn regarding patterns of the periodic table and biomaterials?*

I first gauged students' familiarity with patterns of the periodic table through an audience analysis prior to enacting the *Materials Explorers*™ curriculum so a learner motivational profile of the class could be developed. Students in both the treatment and control classes participated in the same audience analysis. The audience analysis consisted of content-based questions developed by the Franklin Regional School District PLC as well as Likert-scale questions I adapted from Keller's (2009) course interest survey. The audience analysis was again issued after students participated in the *Materials Explorers*™ activities.

4.1.1 Audience Analysis: Planned Curriculum

In terms of content knowledge regarding patterns of the periodic table, the audience analysis revealed that the treatment group scored lower on the pre-test than the control group as shown by the table below:

Table 4. Patterns of the Periodic Table activity pre-test scores

Group	*n*	*M*	*SD*
Treatment	27	6.15	1.46
Control	24	6.65	1.76

Note. The highest possible score on the pre-test was ten.

Qualitatively, the audience analysis revealed the following emergent themes identified in table 5 below:

Table 5. Matrix of emergent themes from the treatment and control groups' perceptions of potential benefits from the Patterns of the Periodic Table activity

Theme	Treatment Group Planned Curriculum	Control Group Planned Curriculum
Understand content on a deeper level	2	5
Learn new information	4	5
Introduce careers	0	1
Make real-world connections	11	6
Increase interest and engagement	7	0
Not sure	0	4

Note. Each number represents the number of responses that pertained to that specific category.

The primary hopes of students in both groups was to learn new information and be able to make real-world connections after participating in the Patterns of the Periodic Table activity.

Additionally, seven students in the treatment group hoped the activity would increase their interest and engagement in science. No students in the control group identified interest or engagement as a potential benefit. However, a handful of students in the control group did explain they were unsure as to how they would benefit from participating in the activity while all of the students in the treatment group were able to identify at least one way they would benefit.

The treatment group's motivational profile revealed that students were motivated prior to engaging in the periodic table activity. The motivation aspect of the treatment group profile was supported by the percentage of students who expressed interest in learning about the science behind superheroes (69%) and the percentage of students who agreed that popular culture references help them make connections between the content they are learning and the real world (85%). The motivational profile of the control group revealed that many students had lower motivation than the treatment group prior to engaging in the periodic table activity. The motivation aspect of the control group motivational profile was supported by the percentage of students who were interested in learning about the science behind superheroes (50%) and the percentage of students who agreed that popular culture references help them make connections between the content they are learning and the real world (76%).

4.1.2 Audience Analysis: Enacted Curriculum

After engaging in the Patterns of the Periodic Table activity, the treatment and control groups showed increases in scores on the audience analysis content-based questions, however the gains were not statistically significant. The results of the audience analysis content-based questions are summarized in the table below:

Table 6. Two-Way ANOVA results for the Patterns of the Periodic Table activity audience analysis

Source	Sum of Squares	dF	Mean Square	F	*p*
Treatment vs. Control Group	1.27	1	1.27	0.4	0.5287
Pre-test vs. Post-test	2.58	1	2.58	0.81	0.3705
Group*Test	1.77	1	1.77	0.56	0.4562
Error	289.92	91	3.19		
Total	295.54	94			

Note. ANOVA = analysis of variance.
*$p<.05$

A two-way analysis of variance was conducted to compare the main effects of the assigned group and the pre and post-tests and the interaction between the assigned group and the pre and post-tests on the type of activity the students engaged in: *Materials Explorers™* or traditional. No effects were statistically significant at the 0.05 significance level. The main effect for the assigned group yielded an F ratio of $F(1,91) = 0.4$, $p = 0.5287$. The main effect for pre and post-test yielded an F ratio of $F(1,91) = 0.81$, $p = 0.3705$. The interaction effect was not significant, $F(1,91) = 0.56$, $p = 0.4562$ when it came to the audience analysis for the periodic table activity, therefore any differences are due to chance.

In terms of content knowledge regarding patterns of the periodic table, the audience analysis revealed that the treatment group barely scored higher on the post-test than the control group as shown by the table below:

Table 7. Patterns of the Periodic Table activity post-test scores

Group	*n*	*M*	*SD*
Treatment	27	6.73	2.01
Control	22	6.70	1.71

Note. The highest possible score on the post-test was ten.

Figure 2 below illustrates the results of the learned curriculum audience analysis in regards to students' perceptions of connecting popular culture to content, specifically superheroes:

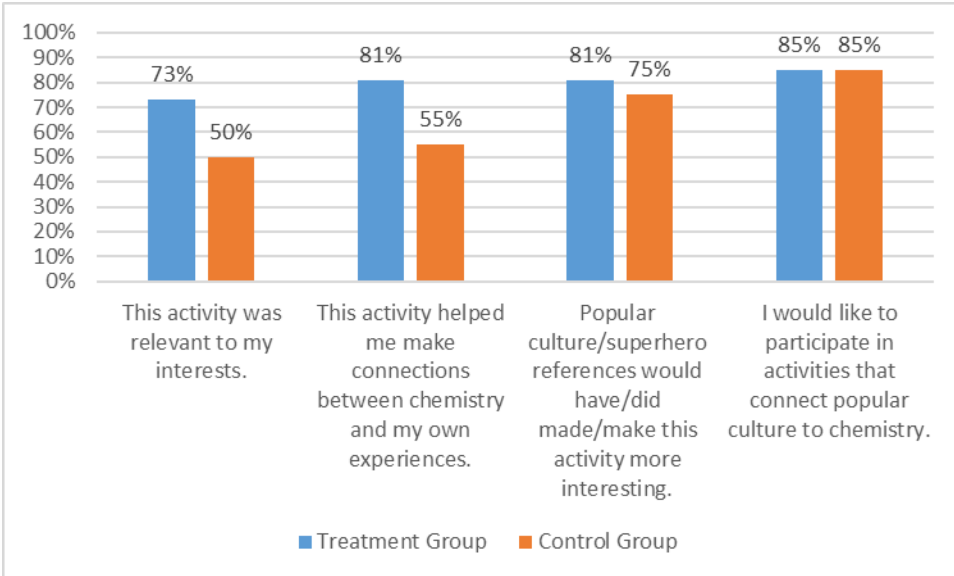


Figure 2. Results of the learned curriculum audience analysis for the patterns of the periodic table activity

The sample sizes for the following results are based on the number of students who indicated they agreed with each statement by selecting yes! or YES! as opposed to no! or NO! Twice as many students in the treatment group (n=20) agreed the activity was relevant to their interests compared to the control group (n=10). Twice as many students in the treatment group (n=21) also agreed the activity helped them make connections between chemistry and their own experiences compared to the control group (n=11). 75% (n=15) of students in the control group felt popular culture references would have made the periodic table activity more interesting compared to 81% (n=19) of students in the treatment group who felt that superhero references did make the activity more interesting. The same percentage (85%) of students in both the treatment and control groups agreed they would like to participate in activities that connect popular culture to chemistry, however this meant that 22 students in the treatment group and only 17 students in the control group agreed with this statement.

Qualitatively, the audience analysis revealed the following emergent benefits after participating in the periodic table activity:

Table 8. Matrix of emergent themes from benefits of participating in the Patterns of the Periodic Table activity

Theme	Treatment Group Learned Curriculum	Control Group Learned Curriculum
Understand content on a deeper level	1	1
Learn new information	9	12
Introduce careers	0	0
Make real-world connections	10	1
Increase interest and engagement	6	2
No benefit	0	2

Note. Each number represents the number of responses that pertained to that specific category.

Learning new information was the only benefit that emerged frequently for both groups after participating in the Patterns of the Periodic Table activity. For the treatment group, two other benefits frequently emerged: making real-world connections and increased interest and engagement. These emergent themes are supported by *figure 2* above. Similar to the results in the learned audience analysis, all students in the treatment group were able to identify at least one way the benefitted through their participation in the activity. Many students in the control group were also able to identify at least one way they benefitted, albeit two students said they did not benefit.

4.1.3 Observation Analysis of the Enacted Curriculum

In an effort to address inquiry question one: *What did students learn regarding patterns of the periodic table* from the enacted curriculum perspective, an assistant principal from Franklin Regional High School acted as an observer during the periodic table activity for both the treatment and control groups. Additionally, I acted as an action researcher and recorded observations during and after the lesson so my observations could be compared to those of the assistant principal. The observation protocol required the assistant principal to provide evidence of the teacher engaging in relevant practices as identified in Keller's (2009) ARCS model. The table below shows the triangulation of the frequencies of the assistant principal's observations compared to mine for each relevant practice during the lesson for the treatment group:

Table 9. Triangulation of observations between the researcher and the observer for the treatment group for the Patterns of the Periodic Table activity

Observation	Frequency of Observation (Observer)	Frequency of Observation (Researcher)
Use a learner analysis to find out learner experiences, interests, and goals.	2	2
Explain how the objectives relate to learners' professional roles	2	2
Explain how the objectives relate to learners' personal interests, experiences, and goals	0	2
Allow time for learner comments and questions, either throughout the class or at specified periods	1	1
Use examples related to current or future jobs	0	2
Use language and terminology specific to appropriate learners and their context	0	2
Incorporate specific learner experiences, interests, or goals into examples	0	2

Note. Key: 0 =Missing, 1 = A little bit, 2 = A lot

The table illustrates many discrepancies between the frequency at which the outside observer recorded the teacher engaging in relevant practices and my perceived frequency therefore the results are divergent. One explanation for the divergent results is that the outside observer did not actually utilize the observation protocol provided, but instead recorded evidence according to Charlotte Danielson's domains for teacher evaluation. This could have occurred because the observer was not trained on the observation protocol due to time constraints. When I received the observations from the assistant principal, they were categorized according to Danielson's four domains: planning and preparation, classroom environment, instruction, and professional responsibilities (The Framework, 2017) as opposed to the relevant practices identified by Keller (2009).

Although the results were overall divergent, both aligned on the first two practices because the outside observer noted that I distributed the audience analyses and posted my learning targets on my bulletin board. The discrepancies between observation frequencies continued during the observation of the control group as shown in the table below albeit the observation of the control group occurred on a different day than the treatment group:

Table 10. Triangulation of observations between the researcher and the observer for the control group for the Patterns of the Periodic Table activity

Observation	Frequency of Observation (Observer)	Frequency of Observation (Researcher)
Use a learner analysis to find out learner experiences, interests, and goals.	2	2
Explain how the objectives relate to learners' professional roles	2	2
Explain how the objectives relate to learners' personal interests, experiences, and goals	0	2
Allow time for learner comments and questions, either throughout the class or at specified periods	1	1
Use examples related to current or future jobs	0	1
Use language and terminology specific to appropriate learners and their context	1	2
Incorporate specific learner experiences, interests, or goals into examples	0	2

Note. Key: 0 =Missing, 1 = A little bit, 2 = A lot

The inconsistencies between myself and the assistant principal were profound for both the treatment and control groups during the patterns of the periodic table activity therefore reliability was not established. Unfortunately, this method could not be improved upon because the assistant principal was unable to observe me during the biomaterials activity due to scheduling conflicts.

4.2 KNOWLEDGE OF BIOMATERIALS

As mentioned in the previous section, an audience analysis helped address *question 1: What did students learn regarding biomaterials?* In terms of content knowledge regarding biomaterials, the audience analysis revealed that the treatment group scored lower on the pre-test than the control group as shown by the table below:

Table 11. Practical Prosthetics activity pre-test scores

Group	*n*	*M*	*SD*
Treatment	25	4.38	1.22
Control	23	4.55	1.27

Note. The highest possible score on the pre-test was ten.

Qualitatively, the audience analysis revealed the following emergent themes identified in table 12 below:

Table 12. Triangulation of emergent themes from the treatment and control groups' perceptions of benefits from the Practical Prosthetics activity

Theme	Treatment Group Planned Curriculum	Control Group Planned Curriculum
Understand content on a deeper level	3	2
Learn new information	8	11
Introduce careers	7	4
Make real-world connections	1	4
Increase interest and engagement	0	0
Not sure	4	1

Note. Each number represents the number of responses that pertained to that specific category.

The primary hopes of students in both groups was to learn new information and be introduced to careers in biomedicine through their participation in the Practical Prosthetics activity. No students in either group identified interest or engagement as a potential benefit. However, a handful of students in the treatment group did explain they were unsure as to how they would benefit from participating in the activity, while all but one student in the control group were able to identify at least one way they would benefit.

The figure below illustrates the results of the planned curriculum audience analysis in regards to students' perceptions of connecting popular culture to content, specifically biomaterials:

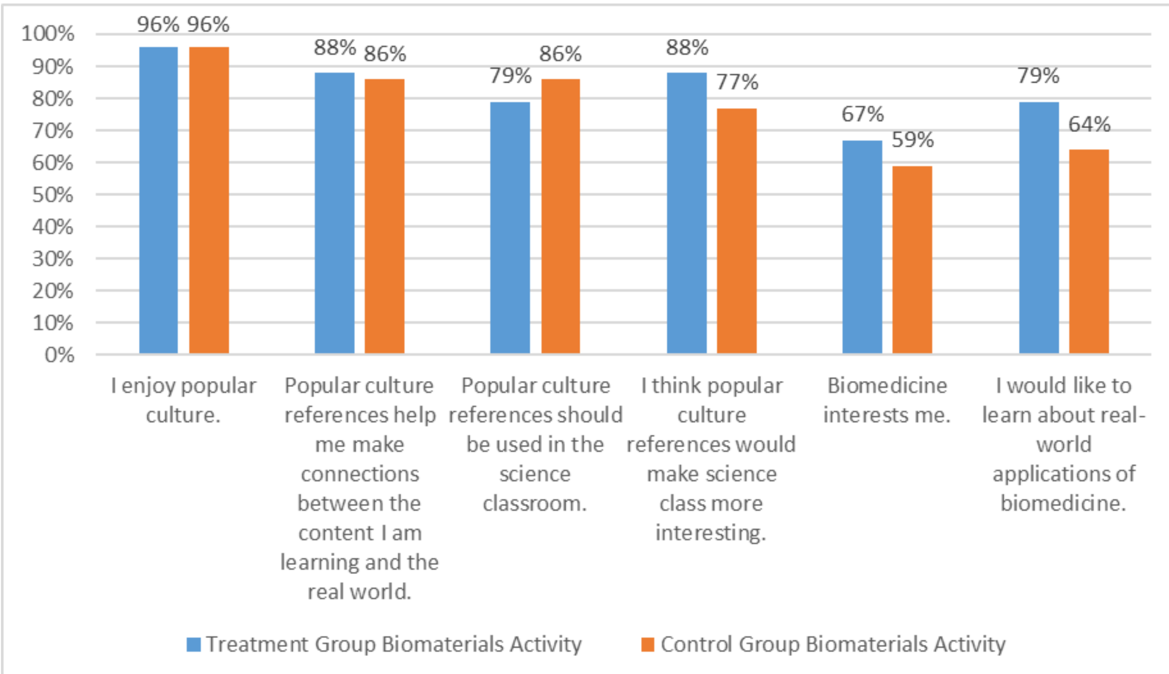


Figure 3. Results of the planned curriculum audience analysis for the Practical Prosthetics activity

The sample sizes for the following results are based on the number of students who indicated they agreed with each statement by selecting yes! or YES! as opposed to no! or NO! 96% of students in both groups (n=23 for treatment group and n=21 for control group) said they enjoy popular culture. Approximately the same number of students in both groups (n=21 for treatment group and n=19 for control group) also agreed that popular culture references help them make connections between the content they are learning and the real world. The motivational profile of the treatment group revealed that students were motivated to learn about biomaterials. This was supported by the fact that 67% (n=16) of students in the treatment group said they were interested in biomedicine and 79% (n=19) said they would like to learn about real-world applications of biomedicine. The motivational profile of the control group revealed that students had lower motivation. Only 59% (n=13) of students expressed interest in biomedicine and only 64% (n=14) were interested in real-world application of biomedicine.

4.2.1 Audience Analysis: Learned Curriculum

After engaging in the biomaterials activity, the treatment and control groups showed increases in scores on the audience analysis content-based questions and the gains were statistically significant. The results of the audience analysis content-based questions are summarized in the tables below:

Table 13. Comparison of pre- and post- audience analysis questions for the Practical Prosthetics activity

Activity	Group	Pre-Score *M*	Pre-Score *SD*	Post-Score *M*	Post-Score *SD*	T-test
Biomaterials	Treatment	4.38	1.22	5.70	1.00	0.0003*
	Control	4.55	1.27	5.32	1.10	0.0413*

Note. * denotes significance. p<.05. N= 48

Table 14. Two-Way ANOVA results for the Practical Prosthetics activity audience analysis

Source	Sum of Squares	dF	Mean Square	F	*p*
Treatment vs. Control Group	0.18	1	0.18	0.13	0.7193
Pre-test vs. Post-test	25.3	1	25.3	18.23	0.0001*
Group*Test	1.76	1	1.76	1.27	0.2629
Error	120.72	87	1.39		
Total	147.96	90			

Note. ANOVA = analysis of variance.
*p<.05

A two-way analysis of variance was conducted to compare the main effects of the assigned group and the pre and post-tests and the interaction between the assigned group and the pre and post-tests on the type of activity the students engaged in; *Materials Explorers*^{TM} or traditional. The main effect for the assigned group yielded an F ratio of F(1,90) = 0.13, *p* = 0.7193. The main effect for pre and post-test yielded an F ratio of F(1,90) = 18.23, *p* = 0.0001. The interaction effect was not significant, F(1,90) = 1.27, *p* = 0.2629 when it came to the audience analysis for the periodic table activity, therefore any differences are due to chance.

The main effect for pre and post-tests yielded an F ratio of F(1,90) = 18.23, *p* = 0.0001 was statistically significant, indicating it is highly unlikely the gain in scores is due to chance alone. Taken together, the T-test and ANOVA results suggest that both biomaterials activities influenced students' content knowledge. Specifically, the results suggest that students who participated in either biomaterials activity had a better understanding of content knowledge due to the enacted curriculum. The significant increase in content knowledge for both groups could be due to the fact that each group engaged in the same task with the only difference being that the task the treatment group participated in referenced *Grey's Anatomy*.

Qualitatively, the audience analysis revealed the following emergent benefits after participating in the Practical Prosthetics activity:

Table 15. Matrix of emergent themes from benefits of participating in the Practical Prosthetics activity

Theme	Treatment Group Learned Curriculum	Control Group Learned Curriculum
Understand content on a deeper level	1	5
Learn new information	5	10
Introduce careers	3	2
Make real-world connections	6	2
Increase interest and engagement	8	3
No benefit	1	0

Note. Each number represents the number of responses that pertained to that specific category.

Learning new information was the only benefit that emerged somewhat frequently for both groups after participating in the Practical Prosthetics activity. For the treatment group, three other benefits frequently emerged: introduction to careers, making real-world connections, and increased interest and engagement. For the control group only one other benefit emerged frequently: understanding content on a deeper level. Unlike the results in the learned audience analysis, all but one student in the treatment group were able to identify at least one way they benefitted through their participation in the activity. All students in the control group were also able to identify at least one way they benefitted.

4.3 RELVANCE OF THE PLANNED CURRICULUM

Making content relevant to the learner can improve motivation and performance (Keller, 2009). Means, Jonassen, and Dwyer (1997) argue that relevant content better meets the needs and goals of individuals which leads to extra effort and ultimately performance. The concept of making content relevant applies to the second inquiry question: *In what ways are the enacted Materials Explorers^{TM} activities relevant to students?* In an effort to answer the second inquiry question, a modified version of Keller's (2009) course interest survey along with adapted questions from the relevance portion of the Instructional Materials Motivation Survey (IMMS) also developed by Keller (2009) (Appendices A and F) was distributed to students in both the treatment and control groups prior to engaging in either activity. A second version of the survey was also distributed to students after they engaged in the activity (Appendices B, C, and G).

4.3.1 Audience Analysis of Patterns of the Periodic Table Activity

The figure below illustrates the results of the planned curriculum audience analysis for both the treatment and control groups in regards to students' perceptions of connecting popular culture to content, specifically superheroes:

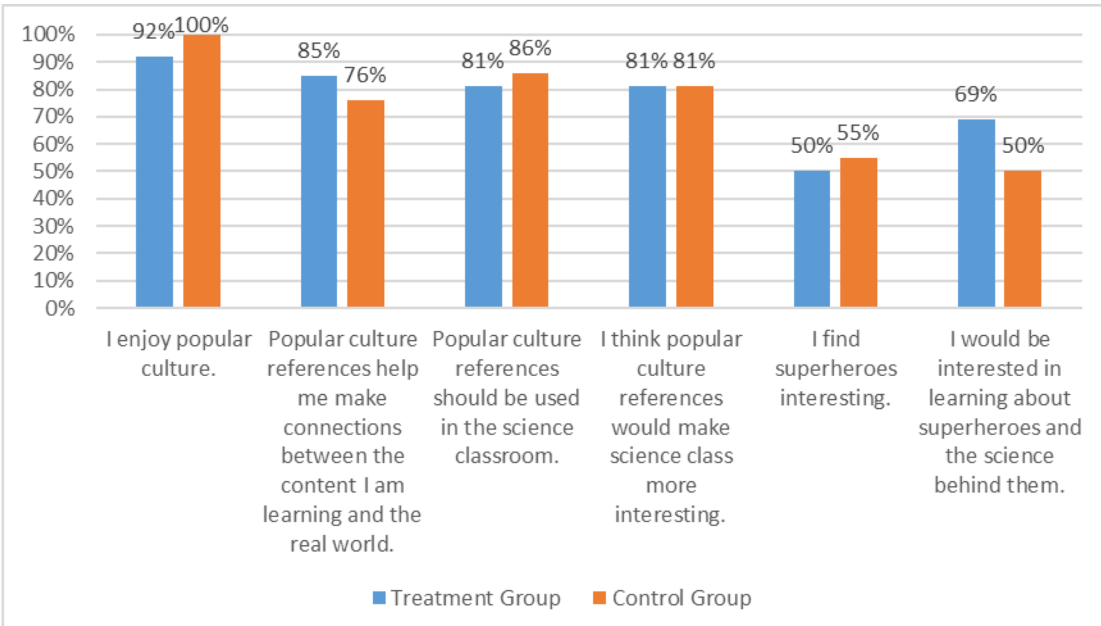


Figure 4. Results of the planned curriculum audience analysis for the Patterns of the Periodic Table activity

The audience analysis interest survey consisted of a range of four answers. The results above reflect the students who selected "yes!" or "YES!" as opposed to "no!" or "NO!" The majority of students in both the treatment and control groups agreed they enjoy popular culture however, 9% or 6 more students in the treatment group (n=22) felt popular culture references help them make connections between the content they are learning and the real world compared to the control group (n=16). The same percentage (81%) of students in both groups agreed popular culture references would make science class more interesting however this percentage was equivalent to twenty-one students in the treatment group and eighteen students in the control group. 81% of students in the treatment group (n=21) thought popular culture references should be used in the science classroom compared to 86% (n=18) of students in the control group. Finally, it was clear superheroes were more relevant to the treatment group than the control group. Eighteen out of twenty-six students in the treatment group expressed interest in learning about superheroes and the science behind them and only ten out of twenty-one students in the control group agreed.

4.3.2 Audience Analysis of Biomaterials

The figure below illustrates the results of the planned curriculum audience analysis for both the treatment and control groups in regards to students' perceptions of connecting popular culture to biomaterials:

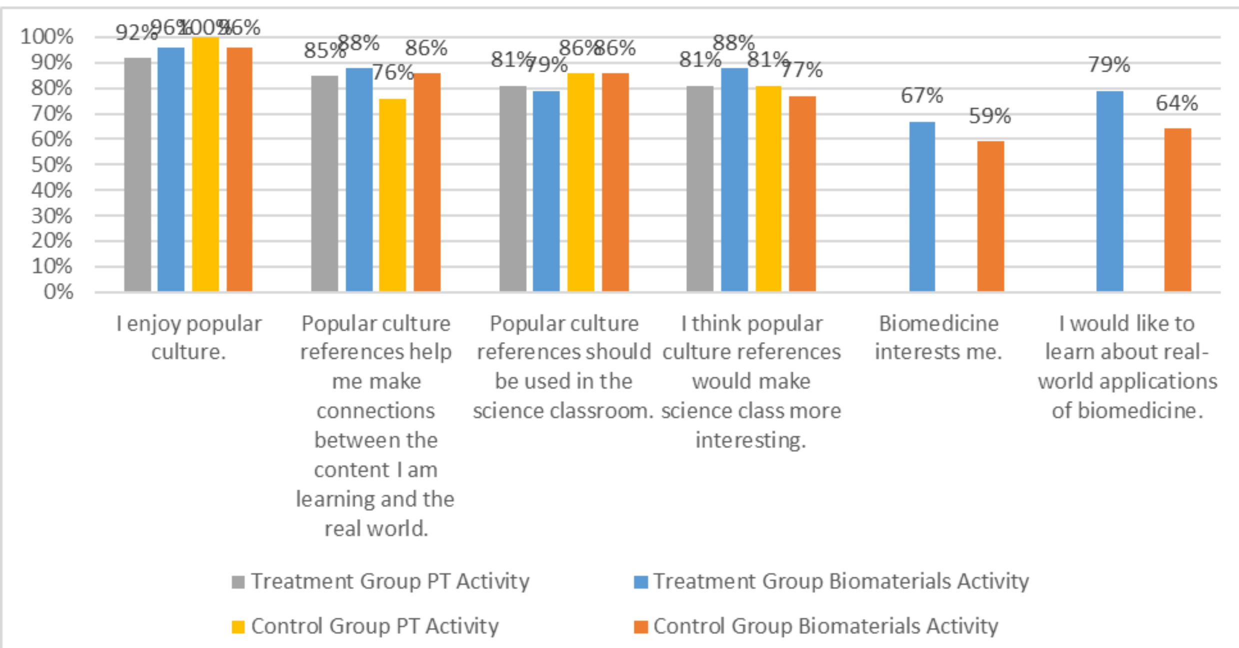


Figure 5. Comparison of the results of the planned curriculum audience analysis in regards to students' perceptions of connecting popular culture to the periodic table and biomaterials

The majority of students in both the treatment and control groups agreed they enjoy popular culture. For the treatment group the percentage of students who agreed they enjoy popular culture appeared to increase by 4% after engaging in the Patterns of the Periodic Table activity and prior to engaging in the Practical Prosthetics activity, while the percentage of students in the control group who agreed they enjoy popular culture appeared to decrease by 4%. However, due to variation in sample sizes, the actual number of students who expressed interest in popular culture for both groups stayed the same. The number of students who felt popular culture references helped them make connections between the content they were learning and the real world stayed the same for the treatment group and increased by three respondents for the control group after engaging in the Patterns of the Periodic Table activity and before engaging in the Practical Prosthetics activity. After engaging in the Practical Prosthetics activity, 88% of students in the treatment group (n=21) agreed popular culture references would make science class more interesting compared to only 77% (n=17) of students in the control group. Two fewer students in the treatment group thought popular culture references should be used in the science classroom compared to the control group. Finally, it seemed biomaterials were more relevant to the treatment group than the control group. 67% (n=16) of students in the treatment group expressed interest in learning about biomaterials and only 59% (n=13) of students in the control group agreed. Based on sample sizes, the difference between the percentages of students interested in learning about biomaterials translated to three additional students in the treatment group compared to the control group. Additionally, 79% (n=19) of students in the treatment group wanted to learn about real-world applications of biomedicine while only 64% (n=14) of students in the control group expressed interest. This percentage difference equated to five additional students in the treatment group.

The data above showed that students found superheroes and biomaterials to be relevant to their everyday lives. According to Keller (1983) relevance is defined as instruction that satisfies students' personal and career goals. Superheroes and biomaterials helped students make connections between the content they were learning and the real world. Exploring superheroes and biomaterials also led to increased interest in science, therefore the two topics were considered relevant. Based on the idea proposed by Haussler and Hoffmann (2000) that a "curriculum which lets the students engage in activities in which they are interested and which presents content in the context of situations meaningful to them is superior to the traditional curriculum" (p. 704) students in the treatment group should have outperformed students in the control group on the post-tests.

4.4 RELVANCE OF THE LEARNED CURRICULUM

The learned curriculum describes the outcomes of the enacted curriculum including the acquisition of skills, understandings, and strategies (Remillard & Heck, 2014). The outcomes of interest in this study were students' perceived relevance of the *Materials Explorers*^{TM} activities and students' attitudes towards science. The statistically significant scores for both the treatment (p=0.0003) and control groups (p=0.0413) on the pre and post assessments shown in table 10 references above, demonstrate that the enacted curriculum was effective in helping students in both groups acquire deeper understanding of the content knowledge. Assessment scores alone however, do not support the outcome of students' perceived relevance of the *Materials Explorers*^{TM} activities. Student responses to the audience analysis Likert-scale questions and course and interest motivation survey need to also be considered when determining whether content was relevant to students, and if so, in what ways.

4.4.1 Audience Analysis of Patterns of the Periodic Table Activity

The figure below illustrates the results of the learned curriculum audience analysis for both the treatment and control groups in regards to students' perceived relevance of connecting popular culture to science content, specifically superheroes:

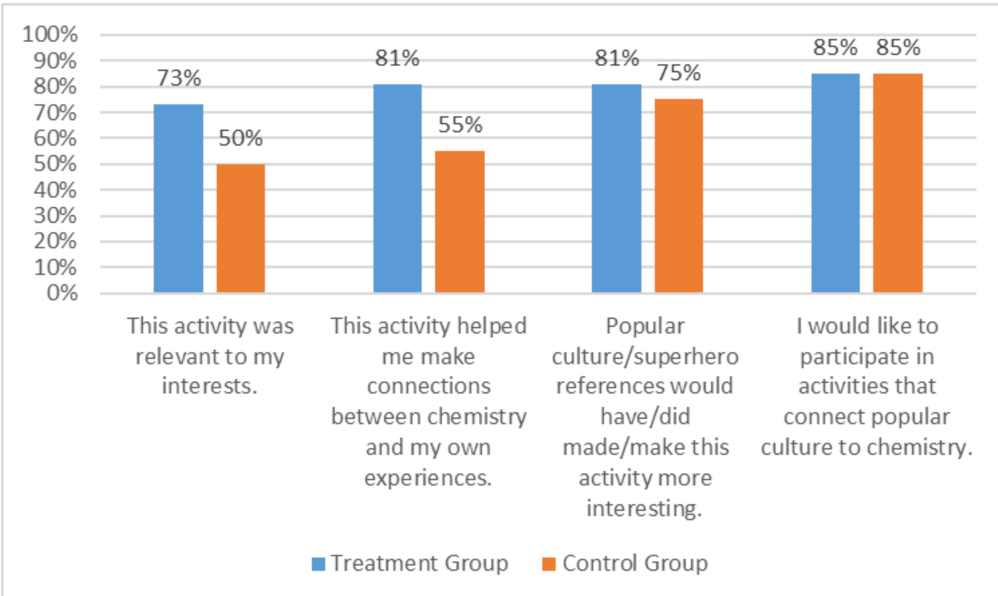


Figure 6. Results of the learned curriculum audience analysis in regards to students' perceived relevance of connecting popular culture, specifically superheroes, to science

The sample sizes for the following results are based on the number of students who indicated they agreed with each statement by selecting yes! or YES! as opposed to no! or NO! After engaging in the Patterns of the Periodic Table activity, 23% more students in the treatment group felt the activity was relevant to their interests compared to the control group. This meant that more than double the amount of students in the treatment group (n=20) compared to the control group (n=10) felt the Patterns of the Periodic Table activity was relevant. 81% (n=21) of students in the treatment group agreed the activity helped them make connections between chemistry and their own experiences while only 55% (n=11) of students in the control group agreed. This meant that once again, double the amount of students in the treatment group versus the control group had an easier time making connections to their everyday lives. 81% (n=19) of students in the treatment group said popular culture references made the activity interesting while 75% (n=15) of students in the control group agreed that had they been subjected to popular culture references during the activity it would have made the activity more interesting. The difference in percentages equated to four additional students in the treatment group. The same percentage (85%) of students in both groups agreed they would like to participate in activities that connect popular culture to chemistry in the future. Although the percentage of students was the same for both groups, that percentage equated to twenty-two students in the treatment group and seventeen students in the control group.

4.4.2 Audience Analysis of Biomaterials

The figure below illustrates the results of the learned curriculum audience analysis for both the treatment and control groups in regards to students' perceived relevance of connecting popular culture to science content, specifically biomaterials:

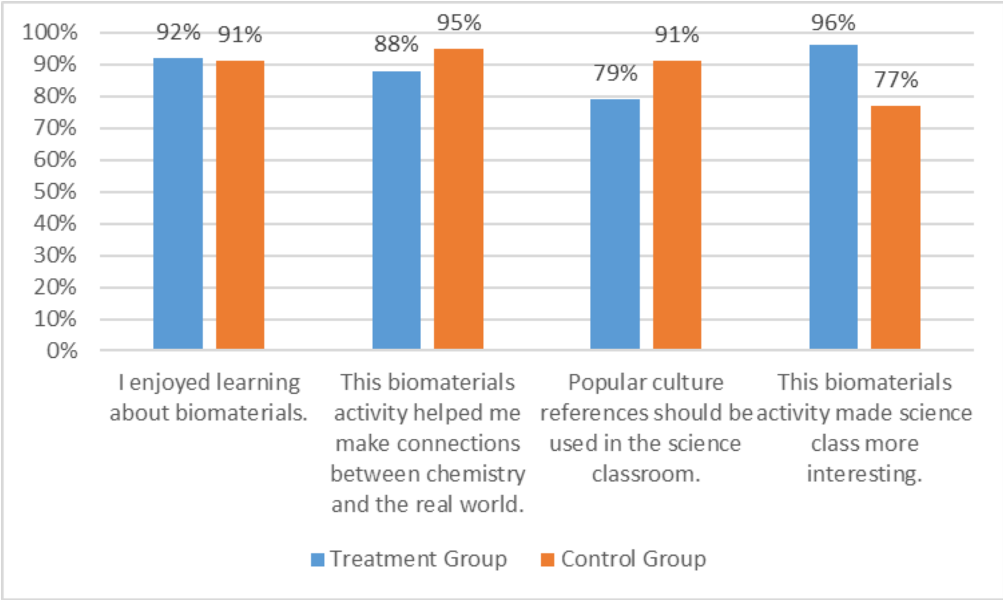


Figure 7. Results of the learned curriculum audience analysis in regards to students' perceived relevance of connecting popular culture, specifically biomaterials, to science

The sample sizes for the following results are based on the number of students who indicated they agreed with each statement by selecting yes! or YES! as opposed to no! or NO! After engaging in the Practical Prosthetics activity, twenty-two students in the treatment group and twenty students in the control group enjoyed learning about biomaterials. Twenty-one students in each group agreed the Practical Prosthetics activity helped them make connections between chemistry and the real world. Twenty-one students in the treatment group had also agreed to the same statement after engaging in the Patterns of the Periodic Table activity compared to only eleven students in the control group. Albeit the percentages differ, nineteen students in the treatment group and twenty students in the control group also agreed popular culture references should be used in the science classroom. All but one student in the treatment group (n=23) expressed that the biomaterials activity made science class more interesting compared to only 77% (n=17) of students in the control group.

The post-test scores in section 4.2.1 support Means, Jonassen, and Dwyer's (1997) argument that "relevant phenomena better fulfill personal needs or goals, thus enhancing effort and subsequently performance" (p. 6). The data above also confirmed the hypothesis set forth by Haussler and Hoffman (2000) who noted that students who engaged in curriculum that was relevant and interesting to them were more successful in retaining content knowledge.

4.4.3 Motivation and Interest Survey

A modified version of Keller's (2009) Course Interest Survey and Instructional Materials Motivation Survey (Appendix E) was distributed to students in both the treatment and control groups after participating in each activity. Keller (2009) notes the CIS "was designed to measure students' reactions to instructor-led instruction and is a situation-specific self-report measure that can be used to estimate learners' motivational attitudes in the context of virtually any delivery system" (p. 277). Keller also suggests that both surveys can be modified to fit specific situations "however, the substance of the items cannot be changed because they are based on specific attributes of motivation" (p. 277). The figures below display the results of the motivation and interest survey issued after each activity for both the treatment and control groups:

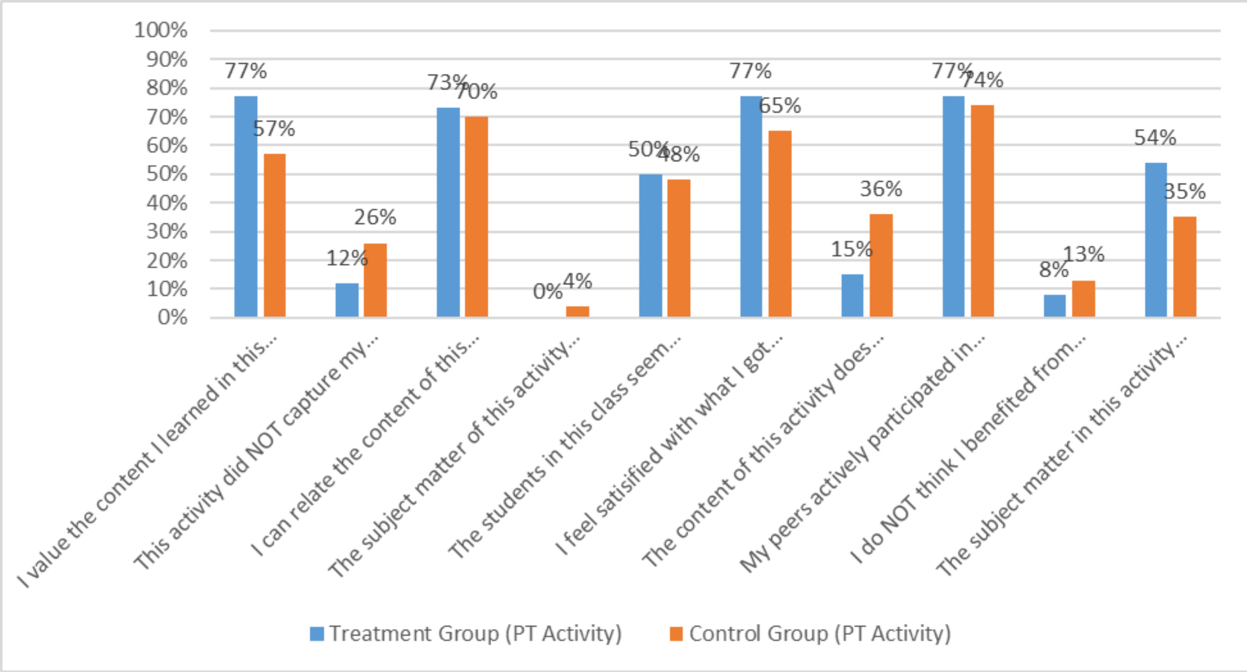


Figure 8. Results of the learned curriculum motivation and interest survey for the Patterns of the Periodic Table activity

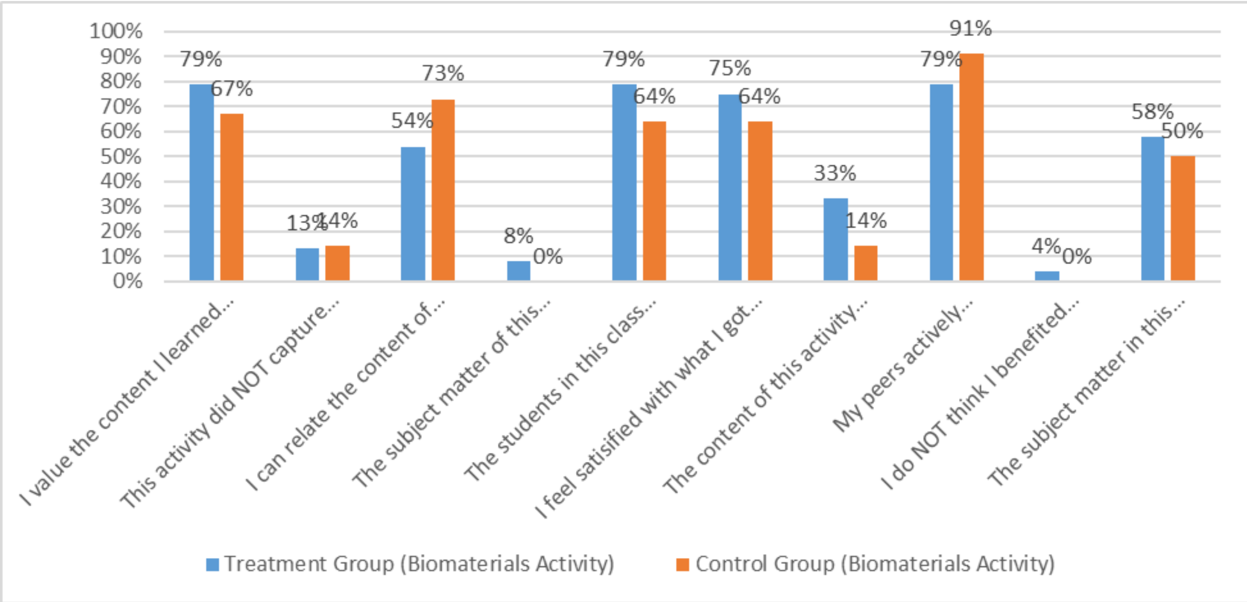


Figure 9. Results of the learned curriculum motivation and interest survey for the Practical Prosthetics activity

The motivation and interest survey revealed that approximately 20% more or seven to eight students in the treatment group valued the content they learned in each activity compared to the control group. The majority of students in both groups agreed both activities captured their attention and few students in each group felt the subject matter of the activities was too difficult for them to comprehend. Nearly half of the students in each group were curious about the content they learned in the periodic table activity, but 79% (n=19) of students in the treatment group were curious about biomaterials as opposed to 64% (n=14) of students in the control group. Perhaps more students in the treatment group were curious about biomaterials because only 54% (n=13) of them could relate what they learned in the activity to what they already knew whereas 73% (n=16) of students in the control group were able to make connections between the biomaterials activity and their knowledge.

4.5 IMPACT OF RELEVANT ACTIVITIES ON STUDENTS' ATTITUDES TOWARD SCIENCE

Hulleman and Harakiewicz (2009) and Gaspard et al. (2015) found that students score higher on assessments and are more interested in a subject when they can connect what they are learning in the classroom to their personal lives. As previously mentioned, motivation profiles were created for both the treatment and control groups in order to ensure students would find superheroes and biomaterials relevant to their everyday lives. The *Materials Explorers*^{TM} activity was then implemented for the treatment group and a traditional activity was implemented for the control group. After engaging in each of the activities, students were questioned about how they benefited from the activity as well as how it impacted their future career plans.

4.5.1 The Impact of the Activities on Students' Attitudes Towards Science

Prior to participating in the Patterns of the Periodic Table activity, the treatment group was optimistic the activity would impact their future career plans. The table below shows the themes that emerged when students were asked how they thought their participation in the activity would impact their career plans:

Table 16. Matrix of emergent themes from potential career impacts prior to engaging in the Patterns of the Periodic Table Activity

Theme	Treatment Group Planned Curriculum	Control Group Planned Curriculum
Make connections	4	2
Increase interest in science	11	5
Career exploration	7	5
No real impact	3	9

Note. Each number represents the number of responses that pertained to that specific category.

Eighteen students in the treatment group anticipated that participating in the activity would either increase their interest in science or allow them to explore various career options. Four students in the treatment group thought that activity might help them make connections to the career path they were interested in and only three students did not think the activity would have an impact. Nine students in the control group thought the activity would have no effect on their career choice. Ten students thought that participating in the activity would either increase their interest in science or allow them to explore career paths and only two students thought the activity might help them connect what they learned to the career path they were interested in.

After participating in the activity nine students in the treatment group and nine students in the control group struggled to identify how the activity impacted their future career plans. The table below shows the emergent career impacts students identified:

Table 17. Matrix of emergent themes from perceptions of career impacts after engaging in the Patterns of the Periodic Table Activity

Theme	Treatment Group Planned Curriculum	Control Group Planned Curriculum
Make connections	6	1
Increase interest in science	5	4
Career exploration	6	5
No real impact	9	9

Note. Each number represents the number of responses that pertained to that specific category. Twelve students in the treatment group explained the activity either connected to their current career interests or allowed them to explore new careers. Five students in the treatment group said the activity increased their interest in science and four students in the control group agreed. Five students in the control group said the activity introduced them to career opportunities while only one student in the treatment group was able to make connections between the content learned in the activity and careers.

The treatment group also identified several ways that their participation in the biomedical activity could impact their future career plans:

Table 18. Matrix of emergent themes from potential career impacts prior to engaging in the Practical Prosthetics Activity

Theme	Treatment Group Planned Curriculum	Control Group Planned Curriculum
Make connections	2	0
Increase interest in science	7	6
Career exploration	10	7
No real impact	5	9

Note. Each number represents the number of responses that pertained to that specific category. Seventeen students in the treatment group thought the activity might either increase their interest in pursuing science or allow them to explore careers in science through their participation. Two students thought the activity might help them connect biomaterials content to their career interests. Five students in the treatment group thought the activity would have no impact compared to nine students in the control group. Thirteen students in the control group thought the activity would increase their interest or help with career exploration and none of the students thought the activity would help them make connections to their current career interests.

After participating in the activity most of the students agreed the activity did not impact their career plans at all as shown in the table below:

Table 19. Matrix of emergent themes from perceptions of career impacts after engaging in the Practical Prosthetics Activity

Theme	Treatment Group Planned Curriculum	Control Group Planned Curriculum
Make connections	1	1
Increase interest in science	4	2
Career exploration	7	4
No real impact	11	11

Note. Each number represents the number of responses that pertained to that specific category.

Eleven students in each group felt their participation in the activity did not have any effect on their future career plans. However, seven students in the treatment group and four students in the control group felt the activity encouraged them to explore various careers. Four students in the treatment group and two students in the control group said the activity was interesting and that it increased their interest in science. One student in each group was able to connect their future career plans to the activity. Additionally, one student in the treatment group and four students in the control group did not respond to this question on the survey.

The figure below illustrates how the *Materials Explorers*^{TM} and traditional activities impacted students' attitudes towards science, specifically students' view of themselves as scientists or engineers and their interest in pursuing science or engineering as a career.

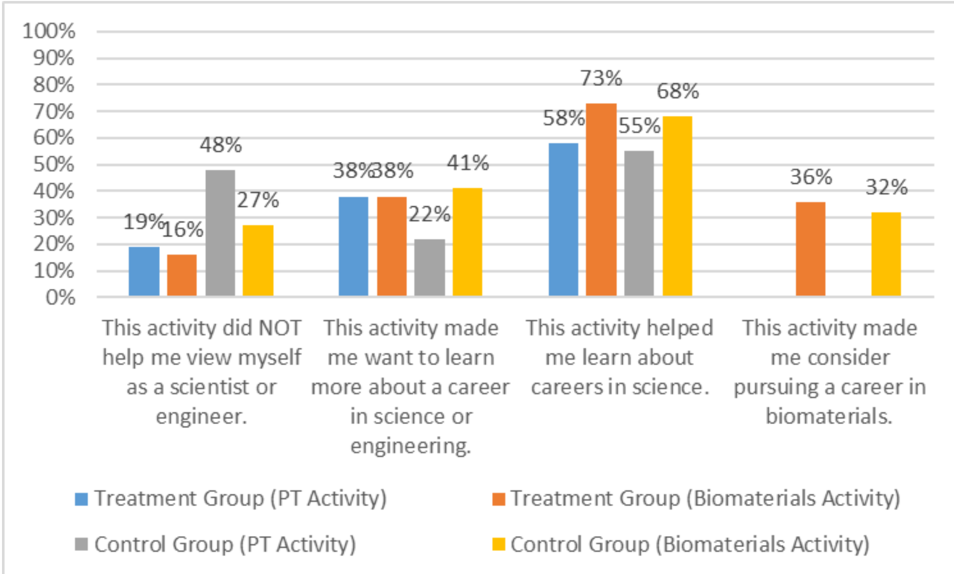


Figure 10. The impact of the *Materials Explorers*^{TM} and traditional activities on students' career aspirations

The sample sizes for the following results are based on the number of students who indicated they agreed with each statement by selecting *mostly true* or *very true* as opposed to *slightly true* or *not true*. After engaging in the Patterns of the Periodic Table activity, five out of twenty-six students in the treatment group and eleven out of twenty-three students in the control group agreed the Patterns of the Periodic Table activity did not help them view themselves as scientists or engineers. The number of students in the treatment group who agreed with this statement after engaging in the Practical Prosthetics activity decreased to four. The number of students in the control group who agreed that the Practical Prosthetics activity did not help them view themselves as scientists or engineers decreased to six. After participating in both activities, 38% (n=9) of students in the treatment group were interested in learning more about careers in science or engineering. After engaging in the Patterns of the Periodic Table activity, only 22% (n=5) of students in the control group expressed interest in learning more about careers in science and engineering. This number however nearly doubled after participating in the Practical Prosthetics activity. An average of sixteen students in the treatment group and fourteen students in the control group felt their participation in the activities helped them learn about careers in science. Finally, nearly the same percentage of students in the treatment and control groups (36% (n=7) and 32% (n=7) respectively) agreed the Practical Prosthetics activity made them consider pursuing a career in biomaterials.

The data above supports the idea that when science courses are relevant to students, they engage in the learning process, which can prompt them to identify with science careers, further the development of their interest in science, and promote science-related academic choices and career paths (Hulleman and Harackiewicz, 2009).

5.0 LIMITATIONS

As with any study, there are limitations in the design and the measures. A significant limitation in this study was that all but one measurement relied on students' self-report measurements. Self-reporting could lead to students' unconsciously attempting to bias their results because they may want to consistently represent themselves. This limitation was cautioned by Osborne (2003) who noted that the difficulty with "assessing the significance and importance of attitudes is that they are essentially a measure of the subject's expressed preferences and feelings" (p. 1054). A second limitation occurred specifically with the generation of the learner motivation profile as a result of the audience analysis. The learner motivational profile did not encompass all dimensions of motivation and is not a rigorous, mathematically based model. The generation of this learner profile was based on measuring motivational levels that were not precise or stable (Keller, 2009).

The only measurement that did not rely on students' self-reporting was the observation protocol (Appendix D), which had its own limitations. The use of an outside observer may have caused the observer effect, where students and the teacher may be influenced by the presence of the observer and behave in uncharacteristic ways. A second limitation of the observation protocol was that the teacher and observer were aware of the treatment and control group's status. This awareness could have biased the behavior of both the teacher and the observer.

Another limitation of the observation protocol is that it is relatively static while the classroom is very dynamic. For example, a student could become very curious or passionate about the content if it strongly correlates to their experiences and interests and asks questions that drive the lesson down a path the instructor was not prepared to go. This hypothetical example occurred in a study conducted by Lefstein and Snell (2011) where students were participating in an *X Factor* themed lesson. The authors explained that the incorporation of this popular culture reference increased student involvement and changed patterns of student participation, however the effects on student learning were mixed. They further cautioned "the same discursive resources that make popular culture attractive as a means of motivating students to engage in classroom activity may in some cases be counterproductive for meaningful and substantive academic learning" (Lefstein & Snell, 2011, p. 41). This unpredictability of the direction of the lesson could make the static and somewhat systematic observation protocol obsolete, particularly during the Powers of the Periodic Table lesson, which references superheroes.

While the hypothetical situation described above did not occur during any of the lessons, an unpredicted limitation of the observation protocol made itself known. I, as the researcher, was unable to properly train the observer prior to him observing the Patterns of the Periodic Table lesson. We had both discussed the protocol and he had access to the protocol prior to observing, however time constraints and previous experiences with different observation protocols led to misinterpretation of the protocol. During the lesson, the observer recorded observations according to Charlotte Danielson's Framework for Teaching. He did not actually utilize the observation protocol I had provided, therefore inter-rater reliability could not be established between the observations recorded by the observer and my self-reflections.

A limitation of the last measurement, a combination of the CIS and IMMS, is that both surveys evaluate situation-specific attitudes, meaning there are many external factors that could influence the responses recorded by the students. Unlike the audience analysis, the motivation and interest survey were only issued after completion of the activity; therefore the results were unable to be compared to students' attitudes prior to engaging in the activity. Another limitation is the size of the sample studied. The sample size was small and inconsistent due to student absences; therefore, the results of this study are not generalizable. A final limitation is that this study focused on connecting popular culture to students' interests, however popular culture is constantly changing. This means that what students find relevant in a particular school year may not reflect the interests of future classes so the activities used in this study may need updated. Additionally, popular culture resources may not be easily accessible to all students and can lead to marginalized student groups. Lefstein and Snell (2011) note that students who do not find curriculum to be relevant may feel alienated.

6.0 CONCLUSIONS AND IMPLICATIONS

The results of this study were not clear-cut, although the results indicated that when science content was made relevant to students' interests through popular culture, students: increased their content knowledge, valued the content they were learning, made connections between the content they were learning and their own experiences, and expressed interest in pursuing a career in science or engineering. The results of this study connected popular culture embedded in the *Materials Explorers*^{TM} activities with achievement, interest, and attitude. Students in the treatment group who engaged in the *Materials Explorers*^{TM} activities showed not only greater gains on both assessments, but outperformed the students in the control group on both post-tests after initially scoring lower on both pre-tests. The gains for both groups were not statistically significant for the patterns of the periodic table activity. Both groups showed statistically significant gains on the pre- and post-tests related to the biomaterials activity, likely due to the fact that nearly all aspects of the activity were the same apart from the background which referenced the television show *Grey's Anatomy* for the treatment group. Another alternative explanation for the significant increase in scores is that students engaged in the Patterns of the Periodic Table activity in February and the Practical Prosthetics activity in May. The time lapse between activities means that both groups were exposed to additional chemistry content and may have been more adapted to my teaching style, influencing the results.

If instruction is to be made relevant to students, educators need to understand what students consider useful, meaningful, and important (Keller, 1983). Students' perceptions of relevant instruction measured through the planned curriculum audience analysis and verified through the learned curriculum audience analysis indicated that many students who were exposed to the *Materials Explorers*™ activities agreed the activities they participated in were relevant to their interests. The students exposed to the *Materials Explorers*™ activities also agreed they had an easier time connecting chemistry to their own experiences, valued the content they were learning, and were interested in participating in additional activities referencing popular culture in the future. On the other hand, students in the control group agreed the activities they participated in would have been more interesting if they had referenced popular culture, had a more difficult time connecting chemistry to their own experiences, and did not value the content they were learning as much as students in the treatment group. However, the students in the control group were eager to participate in future activities connecting popular culture to science. Although an average of five to eight more students in the treatment group compared to the control group agreed with the statements above, the sample sizes in this study were small so the differences between groups are minimal and not generalizable.

An alternative explanation for the results described above is that the students in each group were aware of their status. Knowing their status could have caused the placebo effect for the treatment group since they knew they were engaging in the *Materials Explorers*™ curriculum and ultimately impacted their performance on the self-report measures. Additionally, the treatment group's instruction may have blended into the control group's instruction since the control group was aware of not only their status, but the status of their peers and knew they were receiving different instruction. My own instructional practices may have also influenced the results since even before developing the *Materials Explorers*^{TM} activities, I regularly tried to make content relevant to students' interests.

The results of this study suggest that the *Materials Explorers*^{TM} activities had a positive impact on students' attitudes towards science. After participating in the *Materials Explorers*^{TM} activities, many students in the treatment group expressed possibilities of career aspirations in science or engineering. The majority of students in the treatment group agreed they were able to view themselves as a scientist or engineer while engaging in the activities and expressed interest in learning more about career opportunities in science and engineering. For the Powers of the Periodic Table activity these results were not replicated for the control group. However, for the biomaterials activity the control groups' results were similar to those of the treatment group.

While the results from this study are promising, it is important to be mindful that many influences impacted the results. Almost all of the data was self-reported by students and the only measurement that was not based on self-reported data (the observation protocol) was unable to be used to triangulate data. In addition to the alternative explanations described above, the results could be due to the fact that the treatment and control groups were inequivalent prior to being exposed to the activities. The initial differences between the groups could have influenced the results as much as the activities themselves.

Over 1 million STEM graduates will be needed by the year 2022 (The Progress Report on Coordinating Federal Science, Technology, Engineering, and Mathematics Education, 2016) which means that as educators, we have the responsibility of encouraging and nurturing students' interests in STEM fields. The implications of this study for teachers are that teachers should analyze their audience to learn and understand the motivational profile of their class including their students' perceptions of relevance. The evidence of student growth and ownership from this study support the idea of planning and enacting relevant curriculum. Teachers can use free, developed curriculum such as the *Materials Explorers*^{TM} activities or should tailor instruction to reference popular culture topics students' perceive as relevant. The results of this study can inform teachers or teacher leaders when designing and planning curriculum.

The results of this study not only have the potential to inform teachers and teacher leaders, but have informed my teaching practice as a chemistry educator. I have learned the importance of analyzing my audience, or students, to understand their interests, particularly as they pertain to popular culture, and incorporating their interests into the planned curriculum. I have also learned that making content relevant to students can help increase their content knowledge and their interest in science. Finally, the *Materials Explorers*^{TM} activities have helped expand my repertoire of ways to make chemistry content relevant to students.

In the future, I intend to design planned curriculum and enact curriculum that makes not just chemistry, but science in general as well as engineering, relevant to students' popular culture interests. This intention will be supported by my continued curriculum development work with *Materials Explorers*^{TM} program and The Minerals, Metals, and Materials Society of Pittsburgh. Additionally, I will be piloting a series of *Materials Explorers*^{TM} activities developed in partnership with Arconic in my Academic Chemistry classes during the 2018-2019 school year. The newly developed *Materials Explorers*^{TM} activities developed in partnership with Arconic will also be piloted at several other schools in the Pittsburgh area, yet to be determined. Data similar to that referenced in this study will be collected to better understand the relationships between the planned, enacted, and learned curriculum and students' content knowledge, interest in, and attitudes towards science and engineering.

It is important to note that due to the limitations of the observation protocol mentioned above, this study focused on the planned and learned curriculum (Remillard, 1999). Conclusions regarding the enacted curriculum were unable to be drawn, due to the unreliability of this observational measure. Further research should focus on the impact of the enacted curriculum on students' perceived relevance and attitudes towards science. It is evident that between the planned curriculum and learned curriculum students' engagement in the *Materials Explorers*^{TM} activities led to significant gains in content knowledge, increased interest in science, and positive attitudes towards pursuing science or engineering as a career. In terms of the planned curriculum, five or fewer students in the treatment group compared to nine students in the control group felt that participating in the activity would have no impact on their future career plans. However, in terms of the learned curriculum the same number of students in both groups (nine) felt the activity had no impact on their career plans. Therefore data is needed to reveal the impacts the enacted curriculum has on the learned curriculum. Additional research should also focus on students enrolled in lower level science courses to see if the results are similar since all student participants in this study were currently enrolled in Honors Chemistry.

APPENDIX A

PATTERNS OF THE PERIODIC TABLE AUDIENCE ANALYSIS (DESIGNED CURRICULUM)

1. As you move down a group: Circle your answer.

   Distance from the nucleus (n)

   Increases Decreases Stays the Same

   Number of Protons

   Increase Decrease Stay the Same

   Shielding

   Increases Decreases Stays the Same

   Effective Nuclear Charge

   Increases Decreases Stays the Same

2. As you move down a group which factor is dominant? Circle your answer.

   Number of protons Distance from the nucleus

3. Write a conclusion using the factors above explaining the trend for Coulombic attraction as you move down a group.

4. Which element has the **highest ionization energy**? Circle your answer.

   Cs, K, Li, Rb

5. Which element has the **lowest electronegativity value?** Circle your answer.

   C, F, N, O

6. Which group of elements has the highest ionization energy?

7. Which element has the highest electronegativity value?

Interest Survey

For each of the statements below, circle the response that best characterizes how you feel about the statement. Note that popular culture in this context references music and movies.

	NO!	no!	yes!	YES!
I enjoy popular culture.	NO!	no!	yes!	YES!
Popular culture references help me make connections between the content I am learning and the real world.	NO!	no!	yes!	YES!
Popular culture references should be used in the science classroom.	NO!	no!	yes!	YES!
I think popular culture references would make science class more interesting.	NO!	no!	yes!	YES!
I find superheroes interesting.	NO!	no!	yes!	YES!
I would be interested in learning about superheroes and the science behind them.	NO!	no!	yes!	YES!

1. How do you think you will benefit from participating in this lesson?

2. How do you think this lesson will impact your future career plans?

Additional Comments:

APPENDIX B

PATTERNS OF THE PERIODIC TABLE AUDIENCE ANALYSIS (LEARNED CURRICULUM, CONTROL GROUP)

1. As you move down a group: Circle your answer.

   Distance from the nucleus (n)

   Increases		Decreases		Stays the Same

   Number of Protons

   Increase		Decrease		Stay the Same

   Shielding

   Increases		Decreases		Stays the Same

   Effective Nuclear Charge

   Increases		Decreases		Stays the Same

2. As you move down a group which factor is dominant? Circle your answer.

   Number of protons		Distance from the nucleus

3. Write a conclusion using the factors above explaining the trend for Coulombic attraction as you move down a group.

4. Which element has the **<u>highest ionization energy</u>**? Circle your answer.

   Cs, K, Li, Rb

5. Which element has the **<u>lowest electronegativity value?</u>** Circle your answer.

   C, F, N, O

6. Which <u>group</u> of elements has the highest ionization energy?

7. Which <u>element</u> has the highest electronegativity value?

Interest Survey

For each of the statements below, circle the response that best characterizes how you feel about the statement. Note that popular culture in this context references music and movies.

	NO!	no!	yes!	YES!
This activity was relevant to my interests.	NO!	no!	yes!	YES!
This activity helped me make connections between chemistry and my own experiences.	NO!	no!	yes!	YES!
This activity made me think about careers in science.	NO!	no!	yes!	YES!
Popular culture references would have made this activity more interesting.	NO!	no!	yes!	YES!
I would like to participate in activities that connect popular culture to chemistry.	NO!	no!	yes!	YES!
This activity would have been more relevant if it made connections between careers in science and the content introduced in this activity.	NO!	no!	yes!	YES!

1. How did you benefit from participating in this lesson?

2. How did this activity relate to your future career plans?

Additional Comments:

APPENDIX C

PATTERNS OF THE PERIODIC TABLE AUDIENCE ANALYSIS (LEARNED CURRICULUM, TREATMENT GROUP)

1. As you move down a group: Circle your answer.

   Distance from the nucleus (n)

   Increases Decreases Stays the Same

   Number of Protons

   Increase Decrease Stay the Same

   Shielding

   Increases Decreases Stays the Same

   Effective Nuclear Charge

   Increases Decreases Stays the Same

2. As you move down a group which factor is dominant? Circle your answer.

   Number of protons Distance from the nucleus

3. Write a conclusion using the factors above explaining the trend for Coulombic attraction as you move down a group.

4. Which element has the **highest ionization energy**? Circle your answer.

   Cs, K, Li, Rb

5. Which element has the **lowest electronegativity value?** Circle your answer.

   C, F, N, O

6. Which group of elements has the highest ionization energy?

7. Which element has the highest electronegativity value?

Interest Survey

For each of the statements below, circle the response that best characterizes how you feel about the statement. Note that popular culture in this context references music and movies.

	NO!	no!	yes!	YES!
Superhero references made this activity more interesting.	NO!	no!	yes!	YES!
I enjoyed learning about superheroes and the science behind them.	NO!	no!	yes!	YES!
This superhero activity helped me make connections between chemistry and my own experiences.	NO!	no!	yes!	YES!
Learning about chemistry through the perspective of superheroes made chemistry more relevant.	NO!	no!	yes!	YES!
I would like to participate in more activities that connect popular culture to chemistry.	NO!	no!	yes!	YES!
This superheroes activity helped me learn about careers in science.	NO!	no!	yes!	YES!

1. How did you benefit from participating in this lesson?

2. How did this lesson relate to your future career plans?

Additional Comments:

APPENDIX D

OBSERVATION PROTOCOL

Enacted Curriculum Observation

Frequency	Motivational Delivery Strategy	Evidence
Introduction	Uses a learner analysis to find out learner experiences, interests, and goals	
Introduction	Explains how the objectives relate to learners' professional roles	
Introduction	Explains how the objectives relate to learners' personal interests, experiences, and goals	
Throughout lesson	Allows time for learner comments and questions, either throughout the class or at specified periods	
Throughout lesson	Uses examples related to current or future jobs	
Throughout lesson	Uses language and terminology appropriate to learners and their context	
Occasionally	Incorporates specific learner experiences, interests, or goals into examples	

Teacher Lesson Reflection

1. Did students enjoy the lesson?

2. Were students engaged in the lesson?

3. Did students relate to the content?

4. Did students draw connections between the content and the real-world?

5. Did the lesson relate to students' career aspirations?

APPENDIX E

INTEREST AND MOTIVATION SURVEY

For each of the statements below, circle the response that best characterizes how you feel about the statement, where: 1= Not True, 2= Slightly True, 3= Mostly True, 4= Very True.

	Not True	Slightly True	Mostly True	Very True
I value the content I learned in this activity.	1	2	3	4
This activity did NOT capture my attention.	1	2	3	4
I can relate the content of this activity to what I already know.	1	2	3	4
The subject matter of this activity is too difficult for me.	1	2	3	4
The students in this class seem curious about the subject matter.	1	2	3	4
I feel satisfied with what I got from this activity.	1	2	3	4
The content of this activity does NOT relate to my expectations and goals.	1	2	3	4
My peers actively participated in this activity.	1	2	3	4
I do NOT think I benefited from this	1	2	3	4

activity.				
The subject matter in this activity interests me.	1	2	3	4
This activity did NOT help me view myself as a scientist or engineer.	1	2	3	4
This activity made me want to learn more about a career in science or engineering.	1	2	3	4

1. Currently, which career(s) are you interested in pursuing after high school and why?

Additional Comments:

(cont) Interest and Motivation survey

APPENDIX F

BIOMATERIALS AUDIENCE ANALYSIS (DESIGNED CURRICULUM)

1. Which of the following properties could describe both solids and liquids?
    a. Fluidity
    b. Definite shape
    c. Definite volume
    d. Slow rate of diffusion
2. Particles within a solid
    a. Do not move
    b. Vibrate weakly about fixed positions
    c. Exchange positions easily
3. The intermolecular forces holding particles together are strongest in a
    a. Solid
    b. Liquid
    c. Gas
4. Which of the following has the ability to flow
    a. Solids
    b. Liquids
    c. Gases
5. Which of the following is NOT an example of a viscoelastic material?
    a. Honey
    b. Human tissue
    c. Slinky
    d. Metals at high temperatures
6. Which of the following is an example of a polymer?
    a. Plastic
    b. Amino acids
    c. Monosaccharides
    d. Glycerol

Interest Survey

For each of the statements below, circle the response that best characterizes how you feel about the statement. Note that popular culture in this context references music, movies, and television.

	NO!	no!	yes!	YES!
I enjoy popular culture.	NO!	no!	yes!	YES!
Popular culture references help me make connections between the content I am learning and the real world.	NO!	no!	yes!	YES!
Popular culture references should be used in the science classroom.	NO!	no!	yes!	YES!
I think popular culture references would make science class more interesting.	NO!	no!	yes!	YES!
Biomedicine interests me.	NO!	no!	yes!	YES!
I would like to learn about real-world applications of biomedicine.	NO!	no!	yes!	YES!
I have considered pursuing a career in biomedicine.	NO!	no!	yes!	YES!

Gender Identification: Male Female Other

1) How do you think you will benefit from participating in this lesson?

2) How do you think this lesson will impact your future career plans?

Additional Comments:

APPENDIX G

BIOMATERIALS AUDIENCE ANALYSIS (LEARNED CURRICULUM)

1. Which of the following properties could describe both solids and liquids?
    a. Fluidity
    b. Definite shape
    c. Definite volume
    d. Slow rate of diffusion
2. Particles within a solid
    a. Do not move
    b. Vibrate weakly about fixed positions
    c. Exchange positions easily
3. The intermolecular forces holding particles together are strongest in a
    a. Solid
    b. Liquid
    c. Gas
4. Which of the following has the ability to flow
    a. Solids
    b. Liquids
    c. Gases
5. Which of the following is NOT an example of a viscoelastic material?
    a. Honey
    b. Human tissue
    c. Slinky
    d. Metals at high temperatures
6. Which of the following is an example of a polymer?
    a. Plastic
    b. Amino acids
    c. Monosaccharides
    d. Glycerol

Interest Survey

For each of the statements below, circle the response that best characterizes how you feel about the statement. Note that popular culture in this context references music, movies, and television.

	NO!	no!	yes!	YES!
I enjoyed learning about biomaterials.	NO!	no!	yes!	YES!
This biomaterials activity helped me make connections between chemistry and the real world.	NO!	no!	yes!	YES!
Popular culture references should be used in the science classroom.	NO!	no!	yes!	YES!
This biomaterial activity made science more interesting.	NO!	no!	yes!	YES!
I would like to participate in more activities that connect popular culture to chemistry.	NO!	no!	yes!	YES!
I would like to participate in more biomaterial activities.	NO!	no!	yes!	YES!
This activity helped me learn about careers in science.	NO!	no!	yes!	YES!
This activity made me consider pursuing a career in biomaterials.	NO!	no!	yes!	YES!

Gender Identification: Male Female Other

1) How did you benefit from participating in this lesson?

2) How did this lesson relate to your future career plans?

Additional Comments:

APPENDIX H

PATTERNS OF THE PERIODIC TABLE MATERIALS EXPLORERS™ ACTIVITY

(TREATMENT GROUP)

<u>Powers of the Periodic Table</u>

<u>Background:</u>

Often, when superheroes face seemingly insurmountable odds and unbeatable villains, they gain an advantage by teaming up with other superheroes and combining their unique superpowers. A similar approach can be applied to science and engineering problems. In fact, the minerals, metals, and materials workforce needs professionals from a wide variety of backgrounds to contribute their unique viewpoints and approaches to solve complex problems. Read on about how a few of these individuals are contributing to making our world a better place as members of their own version of a superhero league, The Minerals, Metals & Materials Society.

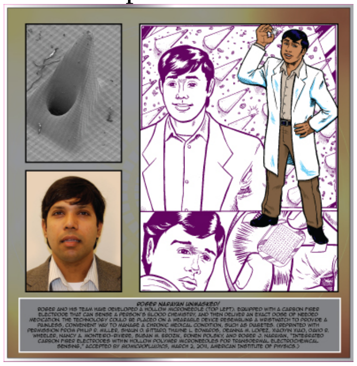
Real-Life Materials Superhero Secret File

Roger Narayan

Origin: Roger Narayan has an M. D. and a Ph.D. in materials science and uses his expertise in both engineering and medicine to create tiny medical devices that reduce the limitations and discomfort caused by injury and illness. He often looks to nature for clues in developing biomaterials that will make these devices as compatible as possible with the human body. For instance, he and his research team at the University of North Carolina and North Carolina State University have used riboflavin—otherwise known as vitamin B_2-With a type of 3D printing process to create structures known as scaffolds that are used to grow cells for use in tissue engineering.

Powers: Roger uses laser-based techniques to fabricate micro- and nanoscale medical devices, layer by layer, from a computer design. This allows the device to be adjusted and customized to the patient and condition that is being treated.

Materials Matter: Improved biomaterials can help injuries heal more effectively, while also lowering the chance of rejection and other side effects that are sometimes associated with implants. many biomaterials and medical devices under development are also intended to help people with chronic conditions better monitor and manage their health at home, reducing their need for more expensive medical services.



Real-Life Materials Superhero Secret File

Tresa Pollock

Origin: American aviation was born in Dayton, Ohio, where the Wright brothers invented the first powered aircraft controlled by a pilot. Tresa Pollock was born not too far from there, and her home state’s many contributions to aeronautics captured her imagination. Her interest really took flight when she saw how engineers designed and built aircraft engines while she was a college co-op student at what is now Rolls-Royce North America. She is today considered a leading expert on high-tech materials for use in the fastest of vehicles, including hypersonic space planes that can travel nearly five times the speed of sound.

Powers: Tresa’s base of operations is the Materials Research Laboratory at the University of California, Santa Barbara-one of the largest and most sophisticated laboratories of its kind. Using lasers, x-rays, ion and electron beams, Tresa and her team reveal the secrets of materials at the level of atoms. With the help of high-performance computers, they take this information to create models that help predict how these materials will operate in the most extreme situations. These models then guide the design of stronger, damage-resistant materials that can take technologies to the next generation of performance.

Materials Matter: The hotter the operating temperature, the more energy-efficient the power system. This is important for just about anything that uses fuel, from commercial aircraft, to power plants, to automotive engines. Scientists and engineers like Tresa create and use advanced laboratory tools and techniques to help them discover, design, and make materials that can be pushed to higher and higher temperatures, reducing harmful environmental emissions and the amount of fuel consumed.

Real-Life Materials Superhero Secret File
Luana Iorio

Origin: Seeing molten metal flow from a crucible during a school field trip was what first lured Luana Iorio to the “materials world.” Today, Luana leads the development of new ways to manufacture components for jet engines at GE Global Research. Using computational tools and advanced manufacturing technology, Luana and her team have figured out how to produce parts that can now help jets fly with more power and fuel efficiency. One of the most exciting moments of her career was the first time she saw a component that she had helped develop be successfully tested on an aircraft engine.

Powers: Luana is an expert in additive manufacturing. In traditional manufacturing, components are usually made by cutting or milling a shape from a large piece of metal. Additive manufacturing uses a computerized plan to build a part from the “bottom up” by depositing one layer of material at a time. This makes it possible to create a very precise, customized part. It also gives Luana and materials scientists like her the ability to better tailor the design of a part to its application in ways that were previously impossible to accomplish.

Materials Matter: Luana and other materials scientists are just now discovering how material properties can be improved through additive manufacturing and other new manufacturing processes. Breakthroughs in these areas will give designers the freedom to create products that are tailor-made to a customer’s unique requirements for such products as medical instruments and implants, industrial tools, jet engines, and space vehicles.

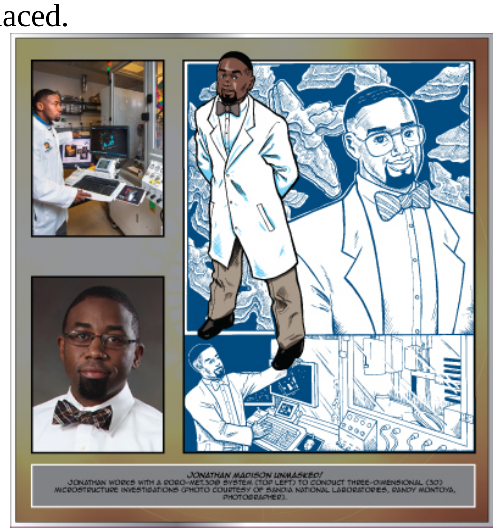
Real-Life Materials Superhero Secret File

Jonathan Madison

Origin: Jonathan Madison is a metallurgist at Sandia National Laboratories who uses advanced computational and experimental tools to understand what is going on inside a material at a very small scale. He then shares that information with others so they can make decisions about how to make the material better suited for a particular use.

Powers: Jonathan gets to use a form of X-ray vision to see inside a material and decide how it should be altered to improve its performance. He uses the data that he gathers to create 3D models of a material's microstructure that help him predict how it might behave under certain conditions. In addition to his scientific powers, Jonathan is an excellent communicator and can work really well with people from different cultures and backgrounds in order to complete a project, solve an engineering problem or meet a goal.

Materials Matter: Scientists and engineers like Jonathan obtain information about the internal state of materials beyond what can be seen with the naked eye. This includes how much damage may be lurking beneath the surface or if a particular process has created unacceptable defects. This knowledge is important for making decisions about whether or not a part needs to be replaced.



Name: ____________________

CID #:________

POWERS OF THE PERIODIC TABLE

Targets

1) Review periodic table trends.
2) Research the careers of various scientists and engineers to gain an understanding of the importance of materials in these professions.
3) Apply your knowledge and understanding of periodic table trends to create a superhero.

Background:

Often, when superheroes face seemingly insurmountable odds and unbeatable villains, they gain an advantage by teaming up with other superheroes and combining their unique superpowers. A similar approach can be applied to science and engineering problems. In fact, the minerals, metals, and materials workforce needs professionals from a wide variety of backgrounds to contribute their unique viewpoints and approaches to solve complex problems. See how a few of these individuals are contributing to making our world a better place as members of their own version of a superhero league, The Minerals, Metals & Materials Society, then create a superhero of your own inspired by the elements of the periodic table.

Real-life Superheroes:

Now that you've learned about some of the materials science and engineering superheroes out there, it's time to create your own character inspired by the periodic table of elements.

As you review the Periodic Table, you may notice that elements are grouped by a certain logic. When Dmitri Mendeleev originally arranged the periodic table in 1869 he did so by atomic mass, but today's period tables look a little bit different. That is because Henry Mosely rearranged the table according to increasing atomic number. This arrangement means that elements in the same group have the same number of valence electrons and exhibit periodicity, meaning they have similar physical and chemical properties. Perhaps some of these properties will inspire your superhero.

Problem:

The Ensemble of Elements, a group of sophisticated superheroes, needs your help. Their membership is dwindling after surviving a surprise attack by trans-dimensional aliens. The Ensemble believes that anyone who understands the materials around them and how they function can become a superhero. They have reached out to you, urging you to develop your sophisticated superhero persona so that you can join them in defeating the alien invaders.

Task:

Your task is to create a superhero persona inspired by one element on the periodic table.

Requirements:

You must create a digital file displaying the following information:

1) Name of superhero
2) Element symbol
3) Element atomic number
4) Element atomic mass
5) Element's location on the periodic table (i.e. group name)
6) Element's electron configuration
7) Physical and chemical properties of element (minimum of 2 each)
8) Strengths of the superhero (based on the element's properties, minimum of 2)
9) Weaknesses of the superhero (based on the element's properties, minimum of 2)
10) Superhero's powers (based on the element's properties, minimum of 2)
11) Pictorial representation of the superhero

Questions:

1) How are the elements arranged on the periodic table?

2) How do valence electrons relate to reactivity?

3) Why is the reactivity of materials particularly important in materials science?

4) Research a material or technology that has made your life better. Who invented it? How long has it been around? How does it improve your quality of life?

5) While scientists and engineers have their sights set on the future, discoveries are made each day that can simplify our lives now. List one material and one technology that you wish currently existed.

Name: ________________________

CID #:_______

Rubric:

CATEGORY	**5**	**4**	**3**	**2**	**Score**
Graphics - Clarity	Graphics are all in focus and the content can be easily viewed and identified.	Most graphics are in focus and the content can be easily viewed and identified.	Most graphics are in focus and the content is easily viewed and identified.	Many graphics are not clear or are too small.	
Creativity	The strengths, weaknesses, and powers are creative and original.	The strengths, weaknesses, and powers are original, but lack creativity.	The strengths, weaknesses, and powers are creative, but not original.	The strengths, weaknesses, and powers are not creative or original.	
Content - Accuracy	All facts are accurately displayed on the project.	4-3 accurate facts are displayed on the project.	2-1 accurate facts are displayed on the project.	No accurate facts are displayed on the project.	
Attractiveness	The project is exceptionally attractive in terms of design, layout, and neatness.	The project is attractive in terms of design, layout and neatness.	The project is acceptably attractive though it may be a bit messy.	The project is distractingly messy or very poorly designed. It is not attractive.	
Grammar/ Spelling	There are no mistakes on the project.	There are 1-3 mistakes on the project.	There are 4-6 mistakes on the project.	There are more than 6 mistakes on the project.	
				Total	____ 25

<u>THE SUPER MATERIALS OF THE SUPERHEROES</u>

Peter Parker may have gained physical superpowers from the bite of a genetically altered spider. But, in *Spider-Man: Homecoming*, it's Peter's own scientific and engineering talents that create Spider-Man's main weapon—synthetic spider webbing that he can trigger from "web shooters" mounted on his wrists. In fact, it's the only part of Peter's original Spider-Man costume that Tony Stark doesn't openly ridicule when he meets him. ("This webbing! Tensile strength is off the charts.") Stark goes on to include his own web shooter technology in the super suit that he designs and gives to Peter (and later confiscates) in the film. Presumably, Stark's web formula is made from ingredients other than what Peter could find in his high school chemistry lab or Aunt May's household supplies.

This is just one of many, many examples of how the heroes and villains in the comic realm rely on materials to boost their powers, provide protection, and even define who they are.

The stories of how these materials are created and used do tend to push and exceed the boundaries of what may be possible. But, they are also rooted in the fact that scientists and engineers are "living superheroes" who change—and save—the world every day.

The real source of Iron Man's power, for instance, is the mind of Tony Stark, a brilliant engineer and wealthy industrialist. In the *Iron Man* and *Avengers* movies, Tony uses computational tools, 3D-visualization, and advanced manufacturing techniques to tailor his collection of Iron Man suits to specific needs. This also means that Iron Man's suits contain very little actual iron. Heavy, dense and prone to rust, it was not a suitable material for his superhero exploits. Instead, Stark has dabbled with various titanium alloys, carbon fiber, and nanotechnology. In *Iron Man 2*, he even synthesized a new element to replace the poisonous palladium core in his Arc Reactor.

Suveen Mathaudhu, a materials scientist at Pacific Northwest Laboratory, professor at the University of California, Riverside, and an avid comic fan, believes that modern processing approaches, advanced microscopy, and computational material design tools characterization technologies, have closed the gap between comic fiction and science reality. "There really is very little reason that we should not be able to microstructurally engineer whatever materials we want for the future," he said.

To illustrate his point, Suveen goes back to the origin story of Captain America's shield, as it was told in the comics (Captain America VI V303 March 1985). As also seen in the *Captain America* and *Avengers* movies, the shield is capable of absorbing, storing, and redirecting all the kinetic energy and vibrations hurled at it. The more energy it absorbs within the bonds between its molecules, the more powerful the material becomes. The fictional element making these unique properties possible is vibranium, obtained from a meteorite that fell to Earth and gave rise to the technological advanced African kingdom of Wakanda—where Black Panther calls home. The shield was born when the vibranium bonded with steel and an unknown catalyst, forming a disc of indestructible alloy that could only be reshaped by molecular rearrangement.

To Suveen, the real hero of this part of the Captain America legend is Dr. Myron MacLain, an American metallurgist. At the urging of President Roosevelt, Dr. MacLain was attempting to develop an indestructible tank armor that would give the Allied forces an edge on the battlefield. While experimenting with vibranium, he nodded off and the alloy mysteriously formed while he slept.

Dr. McLain was never able to recreate the material in his lab again, although Suveen believes he would have fighting chance with technologies from the "real world" that have eclipsed what was being imagined at the time that comic was written. We have control over the atomic world that we didn't have 20 years ago," he said. "Through high-end microscopy tools, we can visualize and manipulate the very microstructure of a material to achieve ultrahigh strength and other truly amazing characteristics. The next frontier is the ability to accurately predict how we can create materials with specific properties. An indestructible material like vibranium does not exist, but we might be able to come close."

Shields, weapons, and superpowers enabled—and in many plot lines, challenged—by science are actually a more recent concept explored in the comic world. The earliest superheroes tended to draw their superpowers from myth and magic—if they had any powers at all. This was particularly the case for Wonder Woman who was introduced to the world in 1942, and as explained in the *Wonder Woman* movie 75 years later, "My mother sculpted me from clay and Zeus breathed life into me." A demi-god among the mythical race of Amazonian women, Wonder Woman's metal bracelets were her main defensive weapon, since they could repel nearly every projectile hurled at her. (And, more recently, she uses the metal bracelets to channel her powers into seismic shockwaves. Take that, Ares.)

The nature of superheroes changed during the Cold War when the world was seized with anxiety by the prospect of nuclear war. Americans embraced technology as a way to make life better, but also realized it could be the means of wiping us out. The superheroes and their villains that came up through this time were metaphors for that conflict. New comic characters were developed as flawed individuals wrestling with a multitude of demons, many of them brought on by scientific recklessness.

Marvel Comics is credited with introducing this contemporary breed of superhero when Reed Richards, the brilliant, but arrogant leader of the Fantastic Four, launched his stolen rocket into space in 1961. He and his crew were accidently bombarded with "cosmic rays," giving them all superpowers, and horribly disfiguring the pilot, Ben Grimm. Most of the Marvel characters in this new era of comics, in fact, started out as scientists—and they weren't the stereotypical "mad geniuses." Reed Richards was the smartest man in the world and used his science for good. But, there was also a dark side to his story. He and characters like him symbolized the overall mood of the country toward science.

Science in service of national defense also became a target of suspicion—while the Steve Rogers character introduced during World War II willingly subjected himself to the experiments that ultimately transformed him into Captain America, the Wolverine character in X-men was kidnapped by a shadowy military operation that forcible implanted adamantium, yet another super-strong fictional alloy, into his skeleton.

"A common theme about this time was the consequences of military research—both good and bad," said Suveen."Materials science technologies were particularly dominant in these stories because they underpin nearly everything and were immediately recognizable to the public."

Many of the stories told through the comic pages of the past are now finding new life (and fans) with a seemingly endless stream of superhero movies and television shows. Characters have been updated, but many of them are still carrying—and even expanding upon—the scientific themes first explored in comic books. But, as dazzling as it is, can this new generation of comic science be believed?

According to Rick Loverd of the National Academy of Science's (NAS) Science & Entertainment Exchange, many creators of fictional universes are very serious about accurately portraying science in their work. The Exchange was established by NAS in 2008 to provide a resource for accurate scientific information to the entertainment industry, and has provide technical consulting to such projects as *Thor* and the *Avenger*s.

"What we have found is that the science is much further ahead of what entertainers usually envision. The creative people who attend our sessions come away inspired and excited to use these cutting edge ideas in their work, said Rick. "Many in the entertainment industry feel it's very important to 'get the science right.' They know that everyone in the audience now has a supercomputer in their pockets. Audiences are more savvy to science than they were in the past, and more questioning of some of the ideas. If what they see on the screen doesn't mesh with information that they have access to online, it takes them out of the story."

"That's not to say that everything in a movie needs to be deadly accurate," Rick continued. "The story will always overshadow the science, but plausible science makes the story line stronger and more engaging. It creates the rules in which those imaginary worlds can logically operate."

Suveen agrees, both from his personal experience as a comic fan and in his attempts to inspire new thinking through comic mythology. "The superhero comic, like any science fiction, is the pulse of scientific possibilities," he said. "People relate to these stories and can tie them uniquely to their own ideas. I often use examples from comics in my presentations as a means of inspiring the next generation of engineers—to get them to think differently about what could be possible and then push to that next level."

"Even the superheroes born with powers have the technical acumen to augment them," Suveenn continued. "The focus in most superhero comic stories is a problem or puzzle that requires science to resolve. The hero is always the person who can figure it out and create the technology that saves the day."

"And, doesn't everyone want to be a superhero, when you come down to it?"

Parts of this article are excerpted from "The Super Materials of the Superheroes" by Lynne Robinson, published in JOM*, January 2012, Volume 64, Issue 1, pp 13-19,* and Comic-Tanium™: The Super Materials of the Superheroes *educational exhibit, presented by TMS, the TMS Foundation, and the Toonseum of Pittsburgh in 2014 and 2015.*

Name:______________________________

Questions:

1) Choose a superhero not already explained in this article who owes his or her powers to science. Research the science behind their powers. Which aspects of their powers are scientifically plausible and which are entirely fictional?

2) Choose a superhero whose powers are *not* created by science. How would you propose recreating some of those powers in the real world?

3) Vibranium, a fictitious element used in Captain America's shield, makes the shield capable of absorbing, storing, and redirecting all the kinetic energy and vibrations hurled at it. The more energy it absorbs within the bonds between its molecules, the more powerful the material becomes. If vibranium were a realistic element, describe where it would fit on the periodic table and why.

4) Peter Parker's web is composed of materials that cannot be found in a high school chemistry lab. Fiberglass however is a material that is easy to obtain and has some of the same desirable properties as Peter Parker's web. Describe the properties of fiberglass that would be useful if it were developed into a web.

5) Peter Parker was not only infamous for shooting webs, but also his ability to quickly scale buildings. Geckos are similar to Peter Parker in that they can "stick" to walls. Explain the science behind this ability and research materials in development that can make scaling walls like Spiderman a reality.

APPENDIX I

PATTERNS OF THE PERIODIC TABLE ACTIVITY

(CONTROL GROUP)

ELEMENT WEBQUEST

Directions

- Follow the specific directions for each section.
- Record your response(s) in the cell provided.

Targets

4) Review periodic table trends.
5) Research an element to discover the real world applications of that element.
6) Apply your knowledge and understanding of periodic table trends to create a poem, haiku, song, or cartoon.

Section I: Web Elements

Go to http://www.webelements.com/

Complete the table below.

Basic Info	
Element Name	

Picture	
Interesting Fact	
"Your Element" Around Us (on the left side of the screen – click on each of the titles below and write a brief summary).	
Geological Information	(consider the abundance in the universe or on earth – paraphrase)
Biological Role	
Calculate how much of your element is in your body	

Section II: The Periodic Table of Poetry

Go to http://www.everypoet.com/absurdities/elements
Find your element's poem and read it.
(If there is no poem for your element, select an element in the same group as yours.)

Copy and paste the poem in the cell below.
Include the APA Citation in the cell below.

Section III: The Periodic Table of Haiku

Go to http://vis.sciencemag.org/chemhaiku/
A haiku is a form of Japanese poetry that follows a 5/7/5 syllable format.
Find and read the haiku for your element.

Copy and paste the Haiku below.
Include the APA Citation below.

Section IV: The Periodic Table of Science Fiction

Go to http://periodictableofsciencefiction.blogspot.com/
Find your element's story and read it.
Write a short (1-2 paragraph) summary about your story in the space provided below.

Story Summary (**DO NOT COPY AND PASTE THE ENTIRE STORY).**
Include the APA Citation below.

Section V: The Periodic Table of Comic Books

Go to http://www.uky.edu/Projects/Chemcomics/
List the title and date of the comic book that features your element.

Title of Comic Book	
Date of Comic Book	

Section VI: Your chance to get creative

Write your own poem or haiku, write a song, or draw a cartoon featuring your element. This section is worth 15 points, but you get to create a rubric for how you would like the points to be distributed. Your rubric must include, at a minimum, the following two categories: Content (does the poem, haiku, song, or cartoon make sense?) and Creativity. In addition to creating a rubric, you must also add a few sentences explaining your rationale for your rubric.

APPENDIX J

BIOMATERIALS ACTIVITY (CONTROL GROUP)

Name: ____________________COW# ____

Biomaterials Activity: Practical Prosthetics

Background:

Viscoelastic materials are those that exhibit both viscous and elastic characteristics. Many of the materials we encounter on a daily basis are viscoelastic. One example of a viscoelastic material is skin. When skin is pinched, it takes a few moments before the skin returns to its original flat position. Another example of a viscoelastic material is a polymer. Polymers, or long chains of molecules, can exhibit properties of both solids and liquids and have a wide variety of uses. A common polymer you may have encountered is Silly Putty. James Wright of General Electric created Silly Putty, although his initial intention was to develop a synthetic rubber compound that could be used to manufacture rubber based products such as tires and boots during World War II. Biomedical engineers experiment with polymers and other viscoelastic materials to support the functioning of a prosthetic. An example of viscoelastic material used to support the functioning of a prosthetic are polyurethanes. Polyurethanes are used in spine stabilizations since their elastic properties allow them to mimic the soft musculoskeletal tissues of the human body.

Problem:

A group of materials scientists suspect that with advancements in prosthetics, Silly Putty can be used as more than a children’s toy and would be beneficial in prostheses. The scientists have asked your class to investigate the properties of Silly Putty and write an evidence based conclusion explaining your findings and the feasibility of using Silly Putty in prosthetics.

Task:

Your task is to replicate James Wright's Silly Putty by using sodium tetraborate, commonly known as Borax laundry detergent and Elmer's glue. You will test what happens when the Silly Putty is stretched, pulled apart, and rolled into a ball. Because the electrostatic forces that hold viscoelastic materials together can change depending on temperature or force applied, you must also test how various forces affect the Silly Putty.

Procedure:

1) Measure 2 tablespoons of water and pour into a small bowl.
2) Measure 2 tablespoons of Elmer's glue and mix with the water.
3) Measure 2 teaspoons of Borax and mix with the glue and water.
4) Use your fingers to thoroughly mix the ingredients until the substance feels like wet putty.
5) Knead the putty until it is completely smooth.
6) Experiment with stretching, pulling apart, and rolling the putty.
7) Use the various objects (golf ball, eraser, weight) to measure stress and strain.
    a. To calculate stress:
        i. Mass the object and convert the mass to kg
        ii. Take the mass in kg times acceleration (9.8 m/s^2) to calculate force
        iii. Measure the length and width of the area in centimeters and convert each measurement to meters. Calculate area using Area = length x width
        iv. Divide load (force) by area

    b. To calculate strain:
        i. Measure the length of the putty
        ii. Slowly stretch the putty, measuring the length of the putty at 3 various points including the length of the initial stretch, the point where the putty becomes opaque, and the point prior to the putty snapping in two
        iii. Take the difference between the original length and the lengths at the 3 various points then divide the differences by the original length

Data:

Object	Mass (kg)	Force (N)	Diameter of indentation (m)	Area of indentation (m^2)	Stress (N/m^2) (Force/Area)

Initial Length of putty	Length of putty at point 1	Length of putty at point 2	Length of putty at point 3	Point 1 Length – Initial Length	Point 2 Length- Initial Length	Point 3 Length – Initial Length
cm	cm	cm	cm	cm	cm	cm
m	m	m	m	m	m	m

Strain (Point 1) Difference/Original Length	Strain (Point 2) Difference/Original Length	Strain (Point 3) Difference/Original Length

Analysis:

1) Record observations for the following:
   a. What happens when the putty is stretched?
   b. What happens when the putty is pulled apart?
   c. What happens when the putty is rolled into a ball?

2) Create a Venn diagram comparing the properties of solids and liquids.

3) Would you classify the putty as a solid, liquid, or both? Why?

4) What is cross-linking and how does it pertain to Silly Putty? (You may have to look this one up!)

5) Compose an **evidence based conclusion** consisting of your observations and the feasibility of using Silly Putty in prosthetics.

Magnesium, Medicine, and Materials Science

They may not be your family doctor, but materials scientists and engineers have a big part to play when it comes to medicine. Can you think of some important materials applications in modern medicine?

Contact lenses, dental implants, pacemakers, and surgical sutures or "stiches" all fall under the category known as *biomaterials*. A biomaterial is any substance that has been modified or developed to be introduced into a biological system for a medical purpose. Some of these applications include replacing diseased or damaged body parts as in the case of hip replacements, enhancing aesthetics through cosmetic implants, and assisting the natural healing process, as with the use of pins or plates.

Many biomaterials are designed to permanently stay in the patient's body but sometimes implants are only needed temporarily—for example, when pins are used to keep bones in place while they heal. In these cases, if a traditional material such as stainless steel, cobalt-chromium, or a titanium alloy were used, the patient would have to undergo an additional surgery after healing in order to remove the implants. Because further operations create additional expense and risks for patients, materials scientists and engineers have been increasingly turning their gaze towards biomaterials that can provide short-term structural support before being safely reabsorbed into the body after the healing process is complete.

The first biodegradable and bioabsorbable implant materials used were the polymers poly- glycolic acid (PGA), poly-lactic acid (PLA), and poly-dioxanone (PDS). However, these materials have limitations. Their low specific strength means that they aren't suitable for load bearing and tissue supporting roles and their radiolucency makes it difficult to accurately place stents that are made of these materials.

Metals, on the other hand, have many of the desirable qualities these polymers lack, such as high strength and fracture toughness. However, most metals are either non-absorbable for the body or can produce toxins as they corrode. One notable exception to this is Magnesium (Mg) and it's an element that has attracted a lot of attention among biomedical researchers.

Magnesium has a high specific strength and an elastic modulus that is closest to the human bone when compared to traditional metallic implant materials. Studies have also confirmed that Magnesium has the ability to stimulate bone growth and healing, and that its degradation leads to harmless corrosion products which are excreted through the urine.

However, Magnesium has its own limitations as an implant material. Under typical atmospheric conditions, it reacts with water to produce a mildly protective film of magnesium hydroxide. Although this film slows corrosion under aqueous conditions, it reacts with chlorine ions present in physiological conditions to produce MagnesiumCl2 and hydrogen gas. This high rate of corrosion can undermine the mechanical integrity of the implant before the bone or tissue has sufficiently healed. Magnesium's low corrosion resistance can also lead to the rapid production of hydrogen gas and the formation of gas bubbles. These bubbles can accumulate around the implant and delay the healing of the tissue or even increase the pH of the area, affecting other pH sensitive physiological processes nearby.

In order to make Magnesium effective for use in bioabsorbable temporary implants, materials scientists need to find a way to keep it from degrading before the patient's bones or tissue have healed enough to support themselves. Efforts to control the corrosion rate of Magnesium have used various processing methods such as purification, alloying, anodizing, and surface coating.

Studies have shown that purification of Magnesium reduces the corrosion rate considerably; however, due to the low yield strength of pure Magnesium, its application in orthopedics and other load bearing applications is limited.

Alloying elements can be added to increase the strength of pure Magnesium but they must be selected carefully to maintain the Magnesium's biocompatibility. Creating a Magnesium alloy with elements such as Iron, Nickel, Copper, and Cobalt actually increases the corrosion rate of the Magnesium while elements such as Aluminum or Zirconium have can lead to long term effects such as dementia or cancer respectively, and rare earth elements such as Cerium, Lutetium, and Praseodymium are generally considered toxic for the human body.

So what materials won't have a high chance of toxicity? Scientists propose choosing materials that are already essential to the human body to serve as alloying elements. Calcium and Zinc are two such elements. They are essential elements in human body that also provide mechanical strengthening in Magnesium-based alloys. Calcium has been reported to improve the corrosion resistance of Magnesium-based alloys in simulated body fluid. Meanwhile, Zinc additions increase the strength of Magnesium-based alloys through precipitation strengthening.

While this approach seems promising, much more research is needed before Magnesium and its alloys can reach their full potential in biological implants. Chemists, materials scientists and doctors will continue to work together to attain the goal of a fully biocompatible and biodegradable Magnesium alloy implant.

Magnesium Article Questions

1) Write out the reaction for magnesium and water.

2) Balance and classify the type of reaction that occurs between magnesium hydroxide and water.

3) What is precipitation strengthening?

4) Scientists are looking towards elements such as Magnesium, Calcium and Zinc because they are already used in the body. How does your body use each of these elements in its day to day functioning?

5) Materials are all around us and even in us. Advancements in biomedical engineering have led to the creation of a variety of implants. There are many challenges that must be overcome to create an implant. Depending on the implant those challenges can include bioabsorption, resistance to corrosion, and durability. Select one of the following implant categories and research the materials that compose the implants and the challenges that accompany them: dental, cardiovascular, brain, spine, and orthopedic.

APPENDIX K

BIOMATERIALS MATERIALS EXPLORERS™ ACTIVITY (TREATMENT GROUP)

Name: ____________________COW# ____

Biomaterials Activity: Practical Prosthetics

Background:

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Problem:

Dr. Karev and Dr. Robbins suspect that with advancements in prosthetics, Silly Putty can be used as more than a children's toy and would be beneficial in prostheses being designed at Grey-Sloan Memorial Hospital. Dr. Karev and Dr. Robbins need you to investigate the properties of Silly Putty and write an evidence based conclusion explaining your findings including the feasibility of using Silly Putty in prosthetics.

Task:

Your task is to replicate James Wright's Silly Putty by using sodium tetraborate, commonly known as Borax laundry detergent and Elmer's glue. Dr. Karev and Dr. Robbins informed you that materials used for prostheses need to endure various forces and temperatures. They have asked you to test what happens when the Silly Putty is stretched, pulled apart, and rolled into a ball, as well as how various forces affect the Silly Putty.

Procedure:

1) Measure 2 tablespoons of water and pour into a small bowl.
2) Measure 2 tablespoons of Elmer's glue and mix with the water.
3) Measure 2 teaspoons of Borax and mix with the glue and water.
4) Use your fingers to thoroughly mix the ingredients until the substance feels like wet putty.
5) Knead the putty until it is completely smooth.
6) Experiment with stretching, pulling apart, and rolling the putty.
7) Use the various objects (golf ball, eraser, weight) to measure stress and strain.
    a. To calculate stress:
        i. Mass the object and convert the mass to kg
        ii. Take the mass in kg times acceleration (9.8 m/s^2) to calculate force
        iii. Measure the length and width of the area in centimeters and convert each measurement to meters. Calculate area using Area = length x width
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    b. To calculate strain:
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m	m	m	m	m	m	m

Strain (Point 1) Difference/Original Length	Strain (Point 2) Difference/Original Length	Strain (Point 3) Difference/Original Length

Medical Research Chart

a. What happens when the putty is stretched?

b. What happens when the putty is pulled apart?

c. What happens when the putty is rolled into a ball?

d. Would you classify this material as a solid or liquid? What properties does it exhibit that led you to classify it as a solid or liquid?

e. How does cross-linking apply to this material (Silly Putty)? (You may have to look this one up!)

f. Final analysis: Would this material be feasible to use in prostheses? Use evidence to support your claim.

☐ YES

☐ NO

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Doctor Signature: _________________________ Date: ______________

Magnesium, Medicine, and Materials Science

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However, Magnesium has its own limitations as an implant material. Under typical atmospheric conditions, it reacts with water to produce a mildly protective film of magnesium hydroxide. Although this film slows corrosion under aqueous conditions, it reacts with chlorine ions present in physiological conditions to produce MagnesiumCl2 and hydrogen gas. This high rate of corrosion can undermine the mechanical integrity of the implant before the bone or tissue has sufficiently healed. Magnesium's low corrosion resistance can also lead to the rapid production of hydrogen gas and the formation of gas bubbles. These bubbles can accumulate around the implant and delay the healing of the tissue or even increase the pH of the area, affecting other pH sensitive physiological processes nearby.

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Magnesium Article Questions

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