IMPACTS OF UNIVERSAL DESIGN FOR LEARNING PRINCIPLES OF SCIENCE ON STUDENTS' PRACTICE OF SCIENCE

by

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ABSTRACT

In this mixed-methods research project, twenty-eight grade 7 and 8 life science students learned content with a treatment of Universal Design for Learning (UDL) strategies across domains of representation, action and expression, and engagement. This project focused on students' ability to apply their learning to novel scenarios and queries. Instruments of measurement included pre and posttests, application questions, science and engineering fair projects, engagement surveys, interview responses, and myriad formative assessments. Normative gains showed insignificant growth overall. Normative gains for students with special educational needs showed significant growth compared to their peers. The suggests that UDL supports students with special educational needs positively but does not adversely affect students without special educational needs. Projects and activities suggest that UDL supports all students' ability to apply ideas in new ways.

INTRODUCTION AND BACKGROUND

Introduction

As someone who loves telling stories, sharing ideas, and engaging in the learning space, teaching was a natural career fit for me. Following an intense undergraduate career in chemistry, I bounced around the world teaching English until I found myself in Miami, Florida. Hearing an advert on the city's public radio station, I learned that Miami-Dade County Public Schools was seeking people with science degrees to become professional educators. Within two weeks, I was in the classroom and two months later, I enrolled in coursework for certification.

It was a heavy load, teaching to learn during the day and learning to teach at night, but the intensity felt familiar. My life as an undergraduate was equally busy: classes in the morning, research after lunch, working in the evening, returning home to study. As a first-year teacher, I felt empowered, engaged, and driven to constantly improve my students' learning gains.

This intensity marked my life as far back as when I was a little girl in elementary school. My family moved every few years. I attended five elementary schools. In each school, my parents attended numerous parent-teacher conferences to discuss a hyper-engaged, precocious yet easily frustrated and impatient student. It was assumed to be discipline-based. We stopped moving when I entered middle school. There, my middle school teachers, able to observe my behavior consistently, formally asked my parents to have me assessed for focus disorders. My parents, overworked as small business owners with four school-age children, lacking both health insurance and financial flexibility, rejected this. Furthermore, they resisted the suggestion they should medicate their daughter. It was never discussed again.

My sister had been insisting I seek assessment for attention-deficit/hyperactivity disorder (ADHD) for over a decade. In February 2023, I began feeling the familiar overwhelm crippling me. Between mounting exhaustion and diminishing successes in the key areas of my life - teaching, graduate studies, community work, family, I was finally motivated to make an appointment for evaluation. My sister was correct, and the diagnosis spurred months of reexamining my life through the lens of ADHD. With regards to my career in education, it emerged that while I was consistently seeking greater understanding of the diverse brains in my classroom, it never occurred to me that I had a diverse brain too. All I knew was that teaching could be positively exhilarating when synergistic, but too frequently I felt overwhelmed by my students. I now could see how, likewise, I must have been overwhelming them. Each member of a classroom, from the students to the teacher, serves as a behavioral mirror for the other, but each has a unique brain dealing with its own varied life complexities, including those of health, home life, economics, faith, language, and social dilemmas, from mere trifles to tragedy. Diversity reigns.

One former student stands out amongst the many. In September 2020, Washington state entered the school year remotely. Before the school year started, a couple contacted me to support their son during this time. Each year, he started a little further behind due to inadequately supported learning and physical differences. The parents wanting me to focus on building his confidence and skill in reading, coaching in the use of assistive tools for dyslexia and visual support, and practicing many of the basic skills he had missed in earlier in his academic career.

The pandemic exacerbated already existing issues, but it also forced educators, families, and students to seek technological solutions for all students. My student experimented with accessibility tools to support his executive function needs like telling time and creating a calendar. He became familiar with read aloud applications to access content and talk-to-text functions so he could provide evidence of learning. His newfound autonomy allowed him to engage more completely in the classroom. More aware of classroom norms and expectations, he completed more work. Now able to show his learning, the student began to enjoy writing papers and organizing his online portfolio of work. With these accessibility tools, his behavior improved.

Despite the enormous benefits technology provides diverse learners, my student experienced challenges most days. It took time to learn how to use newly discovered accessibility functions efficiently and across different platforms. Many of the tools required some level of reading competency to complete an assignment. Furthermore, doing the specific work of building recognition and reading of syllables within words, or phonemes, in support of literacy was exhausting, emotionally taxing, and often physically painful for him. Accessibility tools are important, but it was clear they were not everything. The emotional aspects of my student's interaction with the school day, material, and actors mattered too. This was evident every time I watched his face light up and spirit visibly lift when it was time to meet with a favored teacher and classmates online.

With sadness, I periodically reflected on how my student would not find success in my chemistry class despite my very best teaching practices. His learning differences and needs influenced nearly every aspect of his life. At the time, the best practices I used were the ones I was taught to meet individual educational plans (IEPs) and 504 plans. This meant scaffolding year-round, differentiating daily, and remediating as needed. It meant creating several different lesson plans: one for the average learner and several more for those with accommodations and modifications and unique to each need. It never felt fully satisfactory; not for me and certainly not for my students. Furthermore, with a full classroom of myriad needs, differentiating for specific accommodations was a daunting and time-consuming task.

My student with dyslexia exposed my own pedagogical weaknesses and highlighted my need to fundamentally change my approach to teaching. I wanted more of my students to have a better learning experience with me. During those powerfully reflective months supporting my student, I gathered ideas and strategies to implement in my future science classroom. It was during these 18 months that I encountered Universal Design for Learning (UDL). Its framework provided the necessary shift of perspective.

UDL grew out of an architectural concept of universal design forwarded by the North Carolina State University College of Design. In 1988, architects defined universal design as the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design. Simply put, changes to the physical environment should benefit those they are intended to support while simultaneously benefiting or having a neutral effect on everyone else. In the context of the built environment, a frequently cited example is the curb cut sidewalk. Originally intended for improved access and safety for wheelchair users, in practice they benefit everyone. Wheelchairs users can easily navigate sidewalks and even non-wheelchair users find them beneficial like when pulling a trolley of groceries across the street. This is the goal of universal design: creating systems that support those who need it but implementing them is such a way it does not negatively affect others. Neutrality is the goal but as curb cuts have shown us, we all benefit from them. Accessible sidewalks are now so commonplace we do not pause when seeing them; likely, seeing a non-curb cut sidewalk would seem odd. Another accessibility tool, closed captioning, initially designed for those in the Deaf and Hard of Hearing community is today readily available to all and serves myriad purposes: catching up on the news in loud and crowded airports or watching films on your phone without sound.

In 1984, a year after Macintosh released its first personal computer, five clinicians at a small hospital in Salem, MA began exploring how they could use this latest technology to support students with learning challenges. They formed the Center for Applied Special Technology and over the next few years, developed a partnership with Apple, became an independent organization, and created partnerships with researchers at Harvard University. In 1988, Center for Applied Special Technologies (CAST) began addressing the bigger issue: inaccessible curriculum (CAST, 2023). By 1990, the United States Congress ratified the Individuals with Disabilities Education Act (IDEA) which made available a free appropriate public education to eligible children with disabilities throughout the nation and ensures special education and related services to those children (United States Department of Education, 2023). The formation of the Center, the advent of the personal computer, the architectural concept of universal design, the shift to address curriculum, and the passing of IDEA: these events positioned CAST to develop the framework of UDL.

UDL's three guiding principles address key aspects of teaching and learning for authentic inclusive education. The first principle of UDL asks educators to present content through multiple means of representation. Addressing the recognition networks in the learner's brain, educators reflect on and prepare methods to diversify their presentation of content. The second principle of UDL asks educators to prepare a range of options for students to show evidence of their learning through multiple means of action and expression. Addressing the strategic networks in the learner's brain, educators provide continual feedback to their learners on varied tasks on their path towards mastery of content. The third principle of UDL asks educators to create an environment where all learners can find multiple means of engagement. Addressing the affective networks in the learner's brain, educators and learners work to create a physical and social-emotional connection to the learning community and therefore, developing emotional connection to the content (CAST, 2023).

The primary objective of UDL is to open the classroom and curriculum so that all learners can succeed. If educators teach through the UDL framework, IEPs and 504 plans must still be followed as they are legally binding documents. It is important to acknowledge that not all students get IEPs and 504 plans when they need them. It is a time-consuming process that begins with neuropsychological assessment and is followed by many meetings involving key stakeholders. There are large costs affiliated with assessment, often prohibitively expensive and frequently not covered by insurance. If parents can get an appointment, the waiting list may be months or even years long; if the provider accepts insurance, many people do not have insurance that can cover appropriate assessment. Parents may encounter communication issues if they do not a speak similar language as the provider, and some parents may suffer communication issues because they have little experience with American education, healthcare, and bureaucracy. Some parents have their own learning, physical, or behavioral challenges. Some parents do not get paid leave from work to attend the necessary procedural meetings to establish an IEP or a 504 plan. Emotionally and socially, there remains a stigma towards assessment and subsequent diagnosis in many families and communities. Some students have such unique needs, their classroom learning may be of lower priority than other predominating needs. Some students may lack a safe and stable home life while some may not have parents at all.

These are the students in our classrooms. Differentiating to accommodate and modify for the complexities in their lives in the manner I was trained is a nearly impossible and disappointingly imperfect task. But not differentiating leaves so many behind. The best practice of differentiation relies on the assumption of a normal student, an average learner. UDL is a pedagogical shift and suggests what many educators have long suspected: there is no normal student and there is no average learner. UDL reinforces that learning is for all, and everyone can learn. The shift is seeing the strength inherent in each of our students, rather than approaching diversity as deficit. This project explores the promise of UDL through a mixed-methods research design, incorporating new approaches to content and skill instruction, unique assessment opportunities, and space for student voice in the classroom through surveys and interviews.

This project employs several UDL techniques and instruments designed to measure student success through applying learned content in novel scenarios. The scenarios range from short answer questions, group activities, and student-designed projects. These methods of assessment require higher-order thinking skills like the assessment items on the Program for International Student Assessment (PISA). PISA is an internationally administered exam wherein 15-year-olds apply their knowledge and experience to solve novel problems within the literacy domains of reading, mathematics, and science (Organization for Economic Cooperation and Development, 2023). I first learned of PISA in 2009 and I have been inspired by the challenge it poses. I appreciate the United Nation's Sustainable Development Goal of quality education for all. I have been disheartened by the United States' performance in each cycle. This is why, every year, my primary goal is to see my students apply new content in interesting and new ways. In this, all students are welcome.

Background

This year, I accepted my first private school position with Seattle Hebrew Academy (SHA). SHA is an early childhood through grade eight Jewish day school in urban Seattle, Washington. Aside from the rigors of Judaic Studies and prayers interspersed throughout the learning day, it is a relaxed, community-oriented school. The language of instruction is English, but Hebrew is one of the required courses of the school and some students enter fluent.

At SHA, I teach middle school science to grades 6 through 8. Grade 6 has 16 students, grade 7 has 13 students, and grade 8 has 15 students. There are five general studies teachers in SHA's middle school covering English, Maths, Social Studies, Science, and Hebrew classes. Eleven other teachers round out the curriculum: five Judaic studies teachers, four learning center specialists, and one art and one gym teacher. There are two additional support staff promoting Jewish life and Israeli life in our school. It is an intimate teaching environment, close and supportive.

Because it is a private school, SHA partners with Seattle Public Schools to craft IEPs, but students are not required to have an IEP to receive accommodations and modifications at SHA. Parents are encouraged to have their children tested when teachers observe patterns indicating a learning difference that could use specific supports. The learning center keeps a record of students' neuropsychological tests and teachers can access them upon request. I have 10 students who have been assessed and eight of whom have progressed through the IEP process with Seattle Public Schools with defined accommodations and modifications, affiliated goal-setting, and stepwise progress reporting.

As in every group of students, learner diversity reigns in my small middle school. My greatest hope is always that my students leave my classroom able to apply, confidently and with sound logic, what they have learned to new situations. In my laboratory-based classrooms, the practice of science and engineering is as fundamental as the disciplinary core ideas. Combining these practices with the core ideas form the scaffold for my methodology. I selected methods and activities, assessments, and opportunities for student voice and choice which address the goal of applying ideas to new situations while utilizing UDL's three principles.

For the principle of representation, I am incorporating several UDL checkpoints into the instruction of two units. The success of implementation of this principle will be measured in a multiple-choice assessment, given at the beginning and the end of each unit. For the principle of action and expression, students will be provided with a variety of engaging activities of formative and summative value and provided regular and ongoing feedback on their progress through the unit, aligned with UDL checkpoints. For the principle of engagement, students will be given opportunities to work solo, in pairs, or in small groups by their own choice, aligned with UDL checkpoints. They will have opportunities to share feedback with me in the form of pretreatment and posttreatment surveys, individual interviews, and group interviews.

Focus Question

My focus question was, How do Universal Design for Learning principles affect students ability to apply content in new ways?

CONCEPTUAL FRAMEWORK

Introduction

Between 2010-2012, my professional educator training included coursework and practicals focused on differentiated instruction using the theory of multiple intelligences (TMI) for my regular classes and specific guidance on supporting students with special education needs (SEN) as required by individual education plans (IEPs). I pursued additional training and subsequent endorsement in gifted education where I continued to explore TMI and SEN accommodation and modifications. These three tools served as the foundation for my early career. I was trained to meet the needs of all my learners across the bell curve.

On 7 December 2010, the results from the 2009 administration of Program for International Student Assessment (PISA) were released and my science department was abuzz with their message: American students placed 23rd in science overall, performing one point higher than the mean for participating Organization for Economic Cooperation and Development (OECD) member countries and economic localities. As a department, we started looking at our best practices and asking questions.

A few years later, I left the classroom to pursue an intentional hiatus from science teaching and focus on teaching diverse learners: I became a regular substitute in special education, 504 behavioral support, and functional skills and academics classrooms. Through this, I wanted to learn how to better differentiate my instruction from experienced educators dedicated to serving these students. These experiences supported me as I taught a student with dyslexia, vision issues, and ADHD in a one-on-one environment throughout the coronavirus pandemic. I saw how my student's inability to access the curriculum did not reflect their intelligence nor their understanding of the material. Over those 18 months before they went back to in-person learning, I became fascinated by Universal Design for Learning (UDL) and its principles. Back in the classroom for the school year 2022-2023, I framed my action research project around UDL. I designed two treatment units using UDL principles and guidelines while incorporating defined checkpoints throughout (CAST, 2023). A third treatment focused on my students' ability to design and carry out their own science or engineering projects. Throughout this project, I wanted to know what impact UDL principles had on students' ability to apply content in new ways.

The Value in Diverse Intelligences

In 1983, Howard Gardner proposed his TMI. This theory proposes that, in addition to general intelligence, there are eight other types of intelligence: linguistic, logical-mathematical, visual-spatial, kinesthetic, musical, naturalist, interpersonal, and intrapersonal (Gardner, 2011). In a 2004 review of Gardner's theory, Dr. Branton Shearer of Kent State University explained how a specific intelligence like linguistic is a combination of knowledge, skills, and abilities: a student may be able to craft excellent prose but lack persuasive speaking skills (Shearer, 2004). Intelligence is complex, even when broken down into its many expressions as TMI does.

TMI has received both acclaim and criticism and in a 2006 volume of the journal, Educational Psychology, Dr. Lynn Waterhouse discredited it, claiming it lacked empirical evidence and fell within the realm of folk psychology. Dr. Waterhouse stated that continuing to use Gardner's theory in the classroom constitutes educational malpractice until it can be backed by rigorous research in the same fashion that general intelligence has been supported. She acknowledged that perhaps one of the reasons why educators find TMI appealing relates to its democratizing of intelligence, which intelligence quotient (IQ) struggles to do (Waterhouse, 2006).

In the same volume of Educational Psychology, Gardner and Moran countered Dr. Waterhouse's assertion of lack of empiricism, stating that TMI is a synthetic work, bringing together empirical evidence across fields to create a working explanation for patterns of mind. They explain that TMI was not a definition of intelligence but rather an explanation for how different parts of the brain work together to create holistic intelligence (Gardner & Moran, 2006). Furthermore, where IQ and the assessments scoring it have long been criticized for being racist and elitest, TMI rejects the concept of a fixed intelligence value and casts doubt on beliefs such as an inherited ability to do mathematics. TMI recognizes the intelligence in each child and places positive value on the diversity of their experience and ability (White, 2019).

It is interesting to note that Dr. Gardner did not foresee educators' wholehearted embrace of his theory (Shearer, 2004). TMI focused educators on the individual learner and asked them to differentiate for the diverse strengths each brought to the classroom and thus, increase equity. TMI was the framework for my early career and today, while I still can see my lesson plans through this lens, it is second nature now.

Results from Program for International Student Assessment (PISA)

Since 2000, the OECD has coordinated the PISA. PISA is designed to measure learning that happened both in-class and out-of-class for 15-year-old students, an age generally accepted internationally as the end of compulsory education. It focuses on three domains of literacy: reading, mathematics, and science. It occurs every three years, with a rotating major domain and the others minor. It is hoped that with more data and increasing worldwide participation, countries can reflect upon what makes a strong education system, observe other countries, increase access and equity within their own borders, and work to improve the quality of life for all (OECD, 2023). In this way, PISA aligns with the United Nations Sustainable Development Goal 4: Quality Education (United Nations, 2023).

In the United States, the efforts for each year are coordinated through National Center for Educational Statistics (NCES) which reports its findings. NCES administers two other assessments of science literacy like PISA: Trends in International Mathematics and Science Study (TIMSS) and National Assessment of Educational Progress (NAEP). PISA and TIMSS are both international assessments, sponsored by the International Association for the Evaluation for Educational Achievement (IEA), while NAEP is a national assessment, also known as the Nation's Report Card (IES, 2023). While PISA measures 15-year-olds' overall progress, TIMSS and NAEP measure science content progress in grades 4 and 8, with NAEP adding an additional progress assessment at grade 12 (McGrath, n.d.).

Scientists from countries which administer TIMSS develop the content benchmarks together, while NAEP derives its benchmarks from Common Core Standards (CCS) and Next Generation Science Standards (NGSS), which have been generally adopted in their existing form or in a modified form as state standards across the United States (Dalton et. al., 2022). PISA is unique because of its focus on general science literacy and its application to real world problems (IES, 2023). Science assessment questions from the 2018 computer-based PISA exam include a variety of topics like Claim, Evidence Reasoning (CER) and deriving meaning from images and simulations (Figure 1) (Figure 2) (Figure 3) (OECD, 2018). PISA is said to measure the outcomes of learning and the yield for overall experience of the 15-year-old taking the assessment, rather than the outcome of schooling. These major assessment endeavors, like student growth in content or literacy, organized through the National Center for Educational Statistics (Table 1).

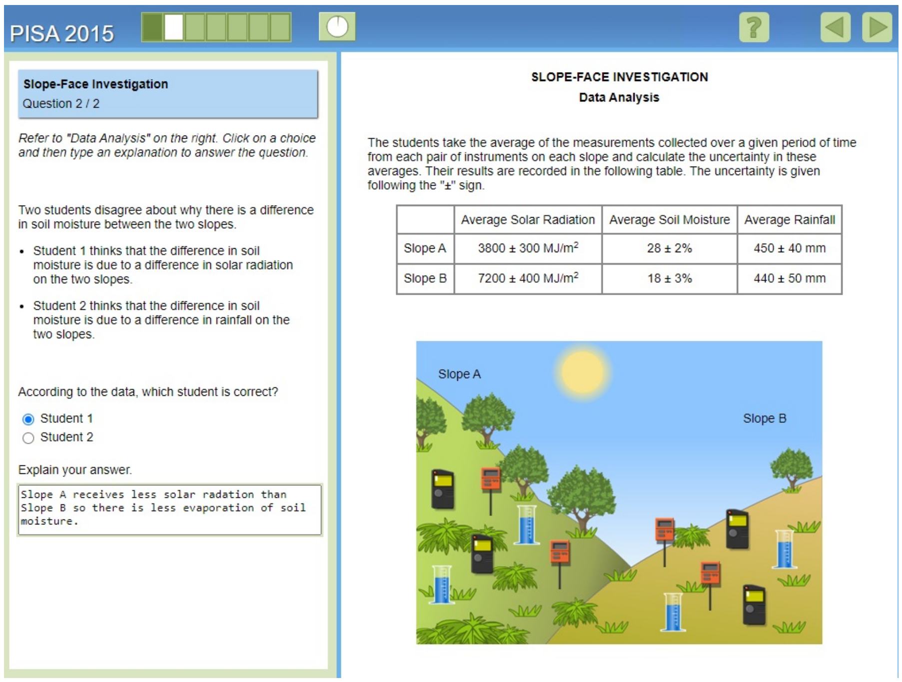

Figure 1. An exam question from the 2018 PISA asks students to evaluate a claim, and then provide evidence and reasoning. Note that students must be familiar with uncertainty in measurements.

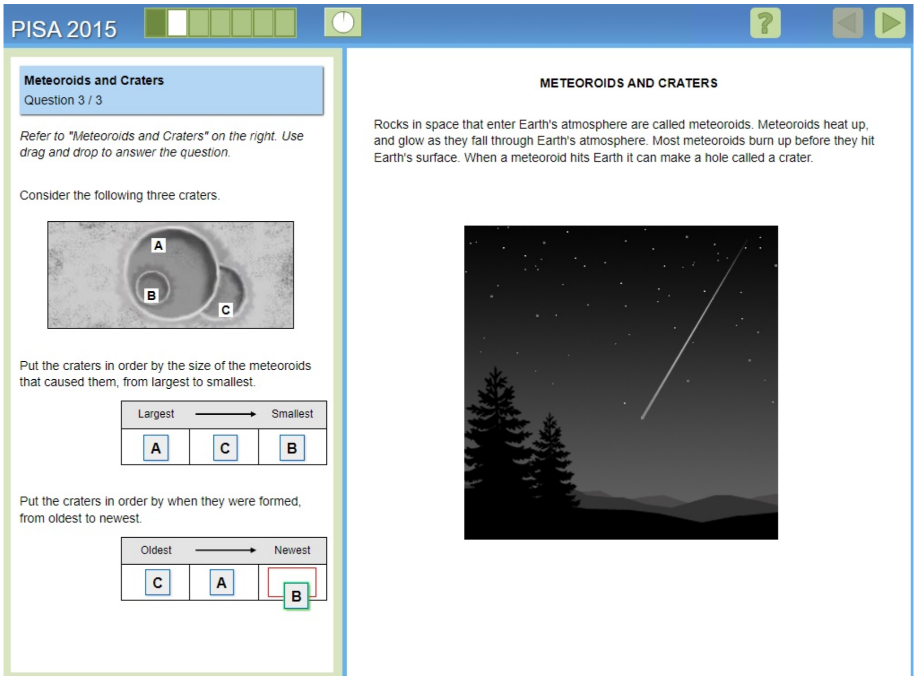

Figure 2. An exam question from the 2018 PISA asks students to derive meaning from an image of craters. Note the format of capturing letters and then moving them into position.

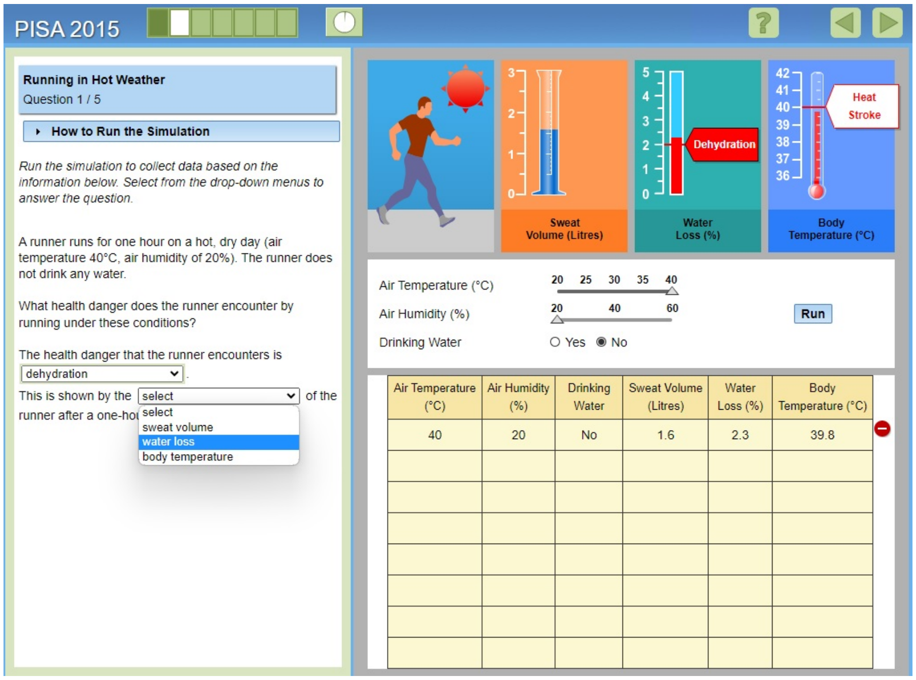

Figure 3. An exam question from the 2018 PISA asks students to run a simulation given predetermined parameters then observe the result. Note the use of drop-down menus.

Table 1. Three science-specific assessments conducted by National Center for Educational Statistics which measure American students' growth in content or literacy.

	PISA	TIMSS	NAEP
Administration	International	International	USA
Scope	General Literacy	Content-Specific	Content-Specific
Grades or Age	15-year-olds	Grades 4,8	Grades 4,8,12
Frequency	Three years	Four years	Approx four years

While PISA assesses science literacy every time it is administered, science literacy serves as the major domain every nine years (IES, 2023). Science literacy was the major domain in 2006, 2015, and 2022. As of this writing, results for PISA 2022 have not been released and are anticipated in December 2023. In 2006, 5600 American 15-year-olds participated in the assessment with 83% responding. In 2015, 5700 American 15-year-olds participated with 89%

responding. In the 2018 PISA, where science literacy was a minor domain, just over 4800 American 15-year-olds participated with 85% responding. In 2006, the United States scaled at 489, lower than the OECD average scale of 500. Twenty-three countries, representing both OECD and non-OECD combined, scored significantly higher than USA. In 2015, the United States scaled at 496, aligned well with the OECD average of 493. Twenty-four countries, representing both OECD and non-OECD combined, scored significantly higher than USA. The results of the most recent PISA with science literacy as a minor domain will be released December 2023 (Table 2). While the United States' performance is consistently flat and hovering about the mean, OECD reports that the number of students scoring a science proficiency less than 2 on a 6-point scale decreased by 5.7% between 2006 and 2018, meaning that the gap between the highest performing students and lowest performing students decreased over these administrations of PISA (OECD, 2023).

Table 2. Summary of American students' participation on the science literacy portion of PISA since it was first administered in 2000. Note that in 2006 and 2015, science literacy was a major domain and the other years, minor.

	No. of Students	No. Responding	Scaled Score
2018	4811	85%	502
2015*	5712	89%	496
2009			497
2006*	5611	83%	502
2003			489
2000			

*Science literacy was a major domain.

PISA is not without criticism. One area that stands out regards the focus on global competence, where competency benchmarks can be seen as reflecting Northern and Western values. While OECD defines global competence as “the ability to interact successfully and respectfully with others and take responsible action toward sustainability and collective well-being,” the concern is for potential othering. Cobb and Couch request educators to look at assessments and specifically measurements of global competence from a decolonialized lens (Cobb & Couch, 2022).

Nonetheless, in its effort to increase the quality of life for all, PISA requires participating countries and schools to be inclusive in their sampling. At the school-level, not the country-level, no more than 5% of a student population may be excluded from participation in the assessment (OECD, 2023). This 5% of students is broken down further: 0.5% may be excluded due to geographic isolation; 2.0% may be excluded due to the specificity of the school, i.e., a school for students with autism; and the remaining 2.5% may be excluded for students with known special education needs. Special education needs (SEN) can be any special educational need: in the United States, this would be a need that requires and IEP or a Section 504 plan, but it could also be a language need, where the student in not fluent in the language of the exam (LeRoy, et al., 2019). Participating countries self-report that they have met the mandates to include students with SEN with no more than 5% excluded, as well as meeting their own country’s standards to include SEN students (OECD, 2012).

Increasing accessibility is on the mind of OECD instrument designers. In a feasibility study presented to the PISA governing board in 2017, researchers asked 37 students from Canada, Dubai, Netherlands, Scotland, and Spain across who experienced a range of special educational needs to provide feedback on a few of the new computer-based test items created by Educational Testing Services (ETS). Results were mixed but the recommendations made to the board were as follows: improve accessibility; develop a modern, computer-based platform; write exams with increased accessibility in both format and content; establish SEN guidelines; and incorporate accessibility training. Of note, in the recommendation for incorporating accessibility training, the study authors reference the United States and our usage of Universal Design for Learning principles in K-12 education (OECD, 2017). While encouraging inclusivity for students with SEN, it is notable the PISA governing body is actively looking for ways to increase accessibility of both the content and format of the assessment and furthermore, that they are looking into UDL.

Disability Rights in the United States

Accessibility in education has been legislated in the United States since the Vocational Rehabilitation Act of 1918. This act provided education, training, and support for injured soldiers and sailors upon their return from World War I. The 1918 act also addressed returning veterans' need for prosthetics, wheelchairs, and other physical aids (Congressional Research Service, 2021). Wheelchair users would have to wait 50 years before they could move between sidewalks though, when the Architectural Barriers Act (ABA) of 1968 was signed into law. ABA required any federal buildings or entities receiving federal funds to ensure access for those with physical disabilities to enter those buildings and use those structures (United States Access Board, 2023). It was out of this law that universal design in the built environment grew (NCSU College of Design, 2023).

The Rehabilitation Act of 1973, Section 501, prevented employment discrimination against individuals with physical disabilities within the federal government or any entity receiving support from it. It required plans for affirmative action to employ individuals with disabilities (United States Equal Employment Opportunity Office, 2021). In that same act but in Section 504, the federal government or entities receiving support from it could not exclude qualified individuals with a physical or intellectual disability from receiving employment, services, or benefits (United States Department of Labor, 2023).

Between Section 504 of the 1973 Rehabilitation Act and the 1975 Education for All Handicapped Children Act (EHA), students with barriers to the classroom began to see their needs addressed in a proactive manner. In 1970, only one in five children with disabilities received an education, with some states excluding them entirely and leaving 1.8 million students nationwide without educational access. Access and educational supports continued to improve through the modernization and expansion of EHA in 1990 (United States Department of Education, 2023). The Americans with Disabilities Act of 1990 incorporated broad protections and inclusions for all persons with disability, with Title II directly requiring all state and local government entities, whether they receive funding from the federal government or not, to provide access to services (United States Department of Justice Civil Rights Division, 2020). EHA was updated at this time to the Individuals with Disabilities Education Act (IDEA), an act that was renewed in 2004. By the school year 2021-2022, more than 7.5 million students with disabilities or potential barriers to learning were being served in schools across the nation (USDOE, 2023).

As an educator, I understand that Section 504 of the Rehabilitation Act and IDEA require me to provide accommodations, modifications, and assistive technology to any of my students who experience a significant barrier to accessing the classroom or the content of my class. Student accommodations reflect how the student accesses curriculum and assessment, i.e., extended time or preferential seating. Modifications address changes to the curriculum, i.e., completing 10 problems instead of 20 or receiving a condensed version of a text. Assistive technology can include a straw pointer, an expanded monitor, or an iPad for communication (Adams State University, 2023).

These accommodations, modifications, and recommended assistive technologies are suggested, discussed, evaluated for their efficacy, and implemented annually by stakeholders in a legally binding individual educational plan (IEP) meeting. Stakeholders required to be at the meeting include, first and foremost, the parents or guardians, at least one of the student's general education and special education teachers, an educational specialist who can interpret results of recent assessments, and a district representative with access to special education oversight. Often, as the student gets older, they may opt to participate in the creation of their plan. Plans can take two forms: an IEP or a Section 504 Plan; a student may have one but not both. There is a simplified and general outline of the differences between the two plans, as adapted from the course, Students with Disabilities (Table 3) (ASU, 2023). Note, IEPS support students with 13 specifically identified barriers to the classroom: autism, deafness, hard of hearing, intellectual disability, orthopedic disability, multiple disabilities, serious emotional disturbance, specific learning disorders (i.e., dyslexia), language impairment, speech impairment, traumatic brain injury, visual impairment, or other health impairments. Section 504 plans broadly support any student with a barrier to learning.

Table 3. A simplified and general summary of the difference between an Individual Education Plan and a Section 504 Plan (ASD, 2023).

	Individual Education Plan	Section 504 Plan
Description	A plan to address a students' specialized education	A plan to remove barriers for a students' physical or learning differences
Relevant Law	IDEA	Rehabilitation Act 1973, Section 504
Eligibility	Student must have a diagnosed, specific disability from a list of 13 identified	Student referred due to any disability that creates a barrier to education
Review	Annually	Annually
Purpose	To set goals, monitor progress, establish new goals to meet student's needs, and their personal goals as they get older	
Cost	Free to Parents/Guardians	

In addition to annual review meetings, educators reflect on IEP and 504 plan progress as part of their lesson planning. Teachers also discuss students' progress when meeting with parents. Since Universal Design for Learning was originally intended to support students with barriers to the classroom, knowing how specific accommodations, modifications, and assistive technologies are implemented, assessed for impact, and renewed for new goals is relevant. This is because an educator who uses UDL must also follow the specific IEP and Section 504 plans for their students as they are written.

Attempts to Create an Inclusive Science Learning Community

In my early career, traditional education started with the assumption of an average learner. It followed that when there is an average learner, there were students who performed above the norm and below the norm. The students below the norm needed accommodations and modifications to meet the norms of the classroom. The specific reasons for these accommodations and modifications were many – physical or cognitive differences, behavioral needs, lack of fluency in the language of instruction, low reading ability, and many others. No matter the reason, students working below the norm had a deficiency and it was up to me to either act as the sage on the stage or guide on the side, providing the curriculum in a differentiated manner with accommodations and modifications to raise them to the norm (Rogers-Shaw, et al., 2018). For students working above the norm, they required accommodations of a different kind: acceleration. These students were permitted to move quickly through the curriculum geared towards the average learner. For them, I provided challenging and more complex lessons beyond the curriculum. When combined with TMI, differentiating each lesson in this manner to deliver the curriculum was seen as good teaching.

Some believe UDL is a further elaboration of this good teaching but based in a 21st century version of Neil Fleming's 1987 theory of learning styles (Boysen, 2021). With learning styles, students took inventories to help them identify the method of learning that worked best for them: visual, auditory, reading/writing, or kinesthetic, collectively known as VARK. The feedback provided by inventories empowered educators to present curriculum in their students' preferred style. Students, also empowered, could select the learning modality that suited them. It was expected that knowledge acquisition improved with increased awareness of learning style but in many studies, this could not be verified (May, 2018). Dr. Guy Boysen, in his 2021 paper, sees some clear parallels between UDL and learning styles. UDL is currently being promoted across the educational lifespan, from early childhood to the tertiary level. He warns against widespread implementation of any educational practice that has not been backed by rigorous critique and plentiful supporting evidence of its effectiveness. He discusses several parallels between UDL and learning styles: a lack of evidence supporting their effectiveness, unclear methods of implementation, too much focus on learner diversity and matching instruction to meet that diversity. He suggests that both theories are based in the oversimplification of the neuroscience backing their frameworks. He calls for rigorous and well-designed studies before wholeheartedly embracing UDL (Boysen, 2021).

Dr. Dave Edyburn of University of Wisconsin-Milwaukee cautioned in 2010 that UDL had not been scientifically validated, yet its principles had been written into the Assistive Technology Act of 1998, now Section 300 of IDEA, which focuses on technological solutions to make the classroom more accessible (USDOE, 2023). Dr. Edyburn recommended developing what he called a diversity blueprint, a tool that could guide instructional designers while creating material with maximum accessibility (Edyburn, 2010). This mirrors the advice given to the PISA governing board in 2017: by what guidelines can we create accessible materials and what role will UDL play (OECD, 2017)? Dr. Edyburn found the principles offered little structure to aide educators in developing their inclusive classrooms. He acknowledged that so-called good teaching has never been able to meet all the needs of all the students and merely preserves the status quo (Edyburn, 2010).

Where nearly all my early career educator training revolved around the status quo, maintained through a normed curriculum and adapted through classroom differentiation, UDL continues to evolve out of current neuroscience research highlighting the complex systems which work together to create knowledge and meaning (CAST, 2023). Neil Fleming's learning styles operated within the framework of a standardized curriculum taught to a classroom of average, deficient, and gifted learners. In contrast, UDL assumes no norm. UDL asks educators to open the curriculum to all learners and truly allow them to construct knowledge through inquiry and collaboration while bringing all their unique learning traits to the classroom (Rogers-Shaw, et al, 2018). UDL says the curriculum is deficient, not the learner (CAST, 2023).

Framework of UDL

It is not intuitive moving away from a traditional, norm-based curriculum background and towards a UDL-based classroom (Edyburn, 2010). Becoming fluent requires skill and practice. Many curriculum companies and administrators attempt to manufacture UDL-moments within educators' lessons but the shift towards UDL comes from the educator alone. This is because teaching and learning within the UDL framework is not transactional, not individualistic, and not behavioristic. Instead, it is communal and collaborative, and most challenging for educators, it means releasing control (Rogers-Shaw, et al., 2018). For those educators beginning their UDL journey, it is helpful to remember that any single lesson is many: a different lesson for every learner in the classroom. This has always been true but through the lens of UDL, educators begin to see themselves as co-agents in the classroom while learners gain a sense of their responsibility in the process (Florian & Beaton, 2018). These seemingly lofty promises cannot be fulfilled through manufactured moments of UDL interspersed throughout a lesson. They require firm grounding in the three principles of UDL. For each principle, there are three guidelines, and each guideline has multiple checkpoints.

The three principles are of representation, action and expression, and engagement (CAST, 2023). Multiple means of each principle are necessary for full implementation of UDL, reminiscent of TMI but considerably more robust. Representation refers to what is being learned, triggering the recognition networks in the brain. Action and Expression refers to how learning is evidenced, triggering the strategizing networks in the brain. Engagement refers to why learners connect with the content, triggering the affective networks in the brain. The result feels a lot like teaching a whole student, not just a standard or a norm.

Each principle is broken down into guidelines, focused around accessing, building, and internalizing, three facets of the same process. Figure 4 summarizes the relationship between principles, guidelines, and a selection of affiliated checkpoints (CAST, 2023). On the CAST website, this is a robust interactive with more checkpoints, elaborations, samples, and examples.

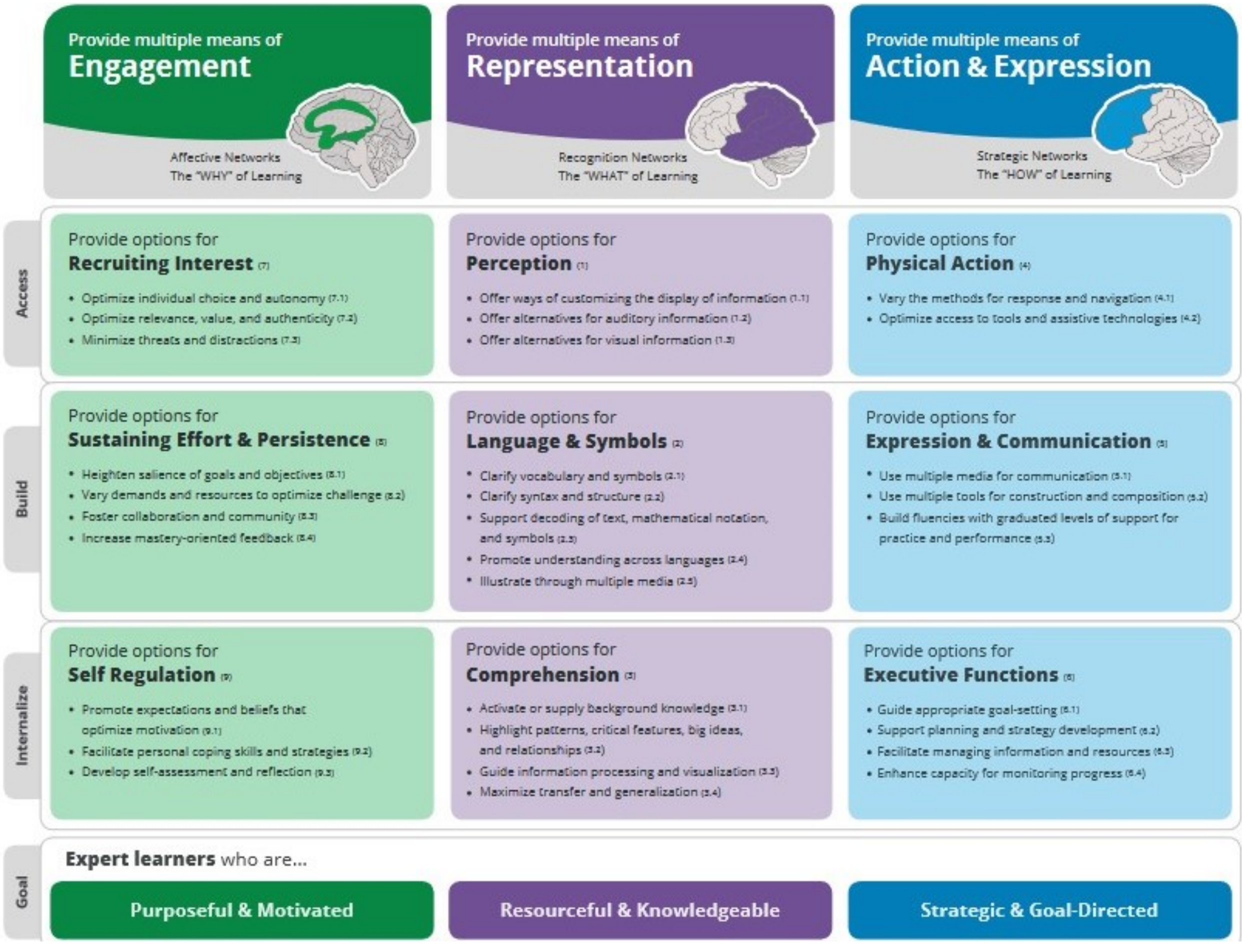

Figure 4. CAST Universal Design for Learning principles, with guidelines and checkpoints (CAST, 2018).

Using the principle of representation as a model, educators can use Figure 4 to reflect on a series of lessons and incorporate relevant checkpoints. For example, educators can provide access to curriculum through the guideline of perception. This can be achieved through checkpoints like offering an auditory version of a reading or manipulatives to illustrate concepts. In the next lesson, educators can help learners build knowledge through the guideline of symbols and language. Here, checkpoints include clarifying vocabulary, explaining grammatical relationships, and defining relevant symbols. To encourage learner internalization, educators implement checkpoints in the guideline comprehension. Educators and learners work to develop shared models, discover patterns, and extrapolate content to new scenarios (CAST, 2023).

This was my focus question: how does the usage of UDL principles affect students' ability to apply information in new ways? While UDL may seem like earlier educational theories of multiple intelligences and the now, mostly ignored, learning styles, it is so much more. Assessments like the internationally administered PISA ask students to use their content knowledge in novel ways. PISA's goal is meeting the United Nations' Sustainable Development Goal for a quality education for all learners. In this, they have begun looking to UDL to guide the development of a blueprint for accessible assessment. UDL originated at a time when the United States was actively working to improve inclusion in its public schools; initially focused on personal computers and assistive technology but over time, advocates expanded their vision as it became clear that the problem was the assumption of an average student. By shifting from seeing learner diversity as deficit to seeing learner diversity as strength and by increasing access through incorporating opportunities for collaborative problem-solving and shared experiences, UDL holds promise to support all learners and allow each to work at their highest level with no loss of rigor. These ideas inspired and guided the development of this mixed-methods action research project.

METHODOLOGY

Demographics

This investigation explored the impact of Universal Design for Learning (UDL) principles on students' ability to apply content in new ways. To do this, students in the treatment unit learned content through multiple means of representation. They engaged with the content through multiple means with learning progress measured by formative and summative assessments delivered through multiple means of action and expression. Two units of the curriculum were selected to be the units of study. In the first unit, Grade 7 (G7) served as the treatment group and Grade 8 (G8) served as the nontreatment group. In the second unit, G8 served as the treatment unit and G7 as the nontreatment. During the first unit, both G8 and G7 participated in the annual Science & Engineering Fair (S&E Fair), where students identified a hypothesis or problem of interest, designed an experiment or prototype, and carried out a full experiment or design cycle. Their results were presented at the fair and were assessed by outside judges. Twenty-eight middle school life science students from Seattle Hebrew Academy (SHA) participated in this study. Both grades studied life science this year.

G7 had 13 students. Four students (31%) had formal individual education plans (IEPs) and two had in-house accommodations and modifications. Three IEP students were diagnosed with specific learning disorders (SLD). One student with an IEP for SLD was trilingual and shifted between all three languages at school and home. One student had a formal diagnosis of ADHD and received in-house accommodations and modifications specific to ADHD but did not have a Section 504 plan. One student had a range of in-house accommodations and modifications but no formal evaluation. In total, six of the 13 students (46%) of G7 received accommodations and modifications.

G8 had 15 students. One student (7%) had a formal IEP for an SLD. Three students had a formal diagnosis of ADHD and received in-house accommodations and modifications specific to ADHD but did not have a Section 504 plan. Two students had a range of in-house accommodations and modifications but no formal evaluation. In total, six of the 15 students (40%) of G8 received accommodations and modifications.

Curriculum was aligned with Next Generation Science Standards, used supplemental materials from Pearson Education's Science Explorations textbooks (2003), and explored concepts in affiliated hands-on explorations.

The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for work with human subjects was maintained (Appendix A).

Treatment

There were two treatment cycles which spanned two units, and one S&E Fair in which both groups participated. G7 and G8 each had an opportunity to participate as a treatment group in one unit and the non-treatment group in the other. Treatment and non-treatment groups maintained equal pacing throughout. Both grades participated in the S&E Fair, receiving equivalent instruction and support based upon individual need for S&E Fair. The treatments to instruction followed UDL checkpoints. These are presented in Table 4, organized by principle. A summary of how each checkpoint was met is explained following Table 4. The instruments used to assess the focus question – what are the impacts of Universal Design for Learning principles on students' ability to apply content in new ways? – are aligned with the UDL checkpoints in Table 4.

Table 4. Checkpoints used in this study aligned by affiliated guidelines and principles (CAST, 2023).

	Principles		
Guidelines	Representation	Action and Expression	Engagement
Access	1.1 Offer ways to customize the display of information	4.1 Vary the methods for response and navigation	7.1 Optimize individual choice and autonomy
	1.2 Offer alternatives to auditory information		7.2 Optimize relevance, value, and authenticity
	1.3 Offer alternatives to visual information		7.3 Minimize threats and distractions
Build	2.1 Clarify vocabulary and symbols	5.1 Use multiple media for communication	8.2 Vary demands and resources to optimize challenge
	2.3 Support decoding of text, mathematical notation, and symbols	5.2 Use multiple tools for construction and composition	8.3 Foster collaboration and community
	2.5 Illustrate through multiple media	5.3 Build fluencies with graduated levels of support for practice and performance	8.4 Increase mastery-oriented feedback
Internalize	3.1 Activate or supply background knowledge	6.1 Guide appropriate goal-setting	9.1 Promote expectations and beliefs that optimize motivation
	3.2 Highlight patterns, critical features, big ideas, and relationships	6.2 Support planning and strategy development	9.2 Facilitate personal coping skills and strategies
	3.3 Guide information processing and visualization	6.3 Facilitate managing information and resources	9.3 Develop self-assessment and reflection
	3.4 Maximize transfer and generalization	6.4 Enhance capacity for monitoring progress	

For the principle of representation, many of the accommodations and modifications were written into students' IEPs. But for the treatment, multiple strategies aimed at increasing access to the content for all students, including reproducing all texts for individual learner's accommodations and modifications but in general, following a 1.5-spaced, size 12 Arial font on a simplified page with minimal distracting images, tables, and figures. When addressing the class and individuals, the rate and content of speech was monitored. Videos used as anchors or instructional content were slowed to 75% of normal speed, watched using closed captioning, and paused to discuss key points. Alternatives to auditory information focused on experiences: reviewing other students' presentations, collaborating on shared projects, and creating shared models that were transcribed into lab notebooks. Alternatives to visual information focused on discussion: tables, diagrams, figures, equations, and models were discussed as pairs, small groups, and as a class; evaluating evidence from labs as a class preceded writing or modeling learning objectives of the labs. To build a foundation for new content, before reading students learned the vocabulary explicitly and previewed the texts for relevant images, tables, and figures. If they chose, students used text-to-speech functions on their computers so they could listen to content and used speech-to-text functions to annotate. To internalize content, it was presented through multiple modalities including text, student presentation, modelling, simulation, laboratory experiments, discussion, and reflection. As connections were made between content and experience, students noted these in their lab notebooks.

For the principle of action and expression, students could provide multiple means of exhibiting their learning growth. Many of these accommodations and modifications were written into students' IEPs. Students identified key ideas decided as a class or individually on paper, in their lab notebooks, or online. They used manipulatives, movement, or drew models or figures to explain their understanding of concepts. Lab experiences gave students the opportunity to explore concepts and class discussions helped them draw meaning. In handwritten responses, students were not marked for spelling or grammar but for typed responses, they were encouraged to use spell and grammar checks. Students participated in peer review for typed and written responses, collaborating on the writing process. Students were provided with graph paper but also taught how to use Google Sheets to create tables and charts. Sentence starters and argument frames guided responses to lab reports, written responses, and discussions. Students received differentiated resources based upon their need and often at their request. When a student found a solution to a problem, they were encouraged to explain their thinking and answer classmates' questions. Timelines for major projects with review points supported their progress, and students wrote goals to achieve along the way. With student permission, models of their work were shared anonymously with the class to illustrate positive progress. Science notebooks documented progress through content and students became successful at maintaining them for maximum usage as a reference tool.

For the principle of engagement, many of the accommodations and modifications were written into students learning plans. All students were provided with autonomy and choice with regards to the level of challenge they wanted to accept. Rewards and recognition, while some came from outside, successes were shared and celebrated, including emails home to parents. For some activities, students chose the order in which they proceeded. Provided with a rubric with learning outcomes, activities involving solo, pair, or group work produced interesting and unique perspectives on content and experiences when presented. For several assignments, students chose their level of collaboration. Content covered during instruction aligned with standards of orthodoxy but still, students had freedom to explore ideas of their own interest. Students were asked for feedback on their experience through surveys designed around Test of Science-Related

Attitudes-adapted (TOSRA) and individual and group interviews. Classroom norms were established at the beginning of the school year but reviewed daily. During discussions, participation by all students was expected but if a student did not know how to respond, they could ask a friend and relay what they learned. Schedules and timelines were provided, and alerts sent home with key deadlines. Communication through Google Classroom and the learning management system occurred as needed. Adjustment to the amount of stimulation in the classroom occurred regularly, with breaks for individual students or the whole class provided. A set of cues established earlier in the year gave all students access to necessary behavior breaks. The process of learning was emphasized and celebrated, rather than focusing on scores and competition. Adherence to the school's positive behavioral intervention system was attempted regularly. Regular, specific feedback and guidance towards mastery was provided. Positive classroom interactions were encouraged, with class breaks provided to settle big energies. At the beginning of each treatment unit, students wrote academic and behavioral goals and revisited them every week to note their progress.

Treatment units began with a TOSRA interest survey and pretest. The pretest included a multiple-choice (MC) portion and a short answer (SA) portion. The next day, students wrote goals for themselves for the unit – either academic or behavioral or a combination – and then were introduced to the treatment's UDL assessment rubric: the Human Tableau. Throughout the unit, UDL techniques were woven into instruction as described in the preceding paragraphs. At the end of each week, students reflected on their goals and then completed an Application Card, a formative assessment focused on applying content learned the week prior to a potential new science or engineering fair project. A week before the Posttest, students presented their Human

Tableau activities. With a study guide, students worked through the content of the unit to prepare for the Posttest. On the day of the posttest, students completed the exam, then answered the same TOSRA-adapted interest survey and responded to an individual interview. The day after the posttest, students revised their exams using their lab notebooks, explained how their thinking changed, and resubmitted their posttests. A whole class posttreatment interview then took place and students shared their experience with the unit.

The Science & Engineering Fair (S&E Fair) was the culmination of science and engineering practices honed since the beginning of the year. Forty-five days before the fair, students were provided with the rubric of their choice, depending on whether they wanted to ask a question or solve a problem. Instruction through the process was scaffolded for all activities from proposal writing, creating tables and charts, completing research, and crafting introductions, methods, and conclusions. On the day of S&E Fair, students were marked by the rubric but received valuable feedback from the engineers, researchers, and professors invited to judge their projects. The two classes participating in this treatment competed for seven awards, which were decided after private deliberation of the judges: Best Overall Engineering Project, Best Overall Science Project, Best G8 Engineering Project, Best G8 Science Project, Best G7 Engineering Project, Best G7 Science Project, and Judges' Choice. Following the S&E Fair, students completed individual interviews and were invited to participate in group interviews about their experience in S&E Fair (Table 5).

Table 5. In the UDL-based classroom created for this project, instruments used to answer the focus question are defined by their affiliated checkpoint and principle (CAST, 2023).

	Checkpoints	Instrument
Representation	1.1 Offer ways to customize the display of information	MC Exam
	1.2 Offer alternatives to auditory information	Human Tableau, S&E Fair Rubrics
	1.3 Offer alternatives to visual information	
	2.1 Clarify vocabulary and symbols	S&E Fair Rubrics
	2.3 Support decoding of text, mathematical notation, and symbols	Exam Revisions
	2.5 Illustrate through multiple media	
	3.1 Activate or supply background knowledge	
	3.2 Highlight patterns, critical features, big ideas, and relationships	S&E Fair Rubrics
	3.3 Guide information processing and visualization	
	3.4 Maximize transfer and generalization	
Action and Expression	4.1 Vary the methods for response and navigation	Human Tableau, S&E Fair Rubrics
	5.1 Use multiple media for communication	Human Tableau, S&E Fair Rubrics
	5.2 Use multiple tools for construction and composition	
	5.3 Build fluencies with graduated levels of support for practice and performance	Human Tableau, S&E Fair Rubrics
	6.1 Guide appropriate goal setting	
	6.2 Support planning and strategy development	S&E Fair Rubrics
	6.3 Facilitate managing information and resources	
	6.4 Enhance capacity for monitoring progress	
Engagement	7.1 Optimize individual choice and autonomy	Application Cards, Human Tableau, S&E Fair Rubrics
	7.2 Optimize relevance, value, and authenticity	Application Cards, Human Tableau, S&E Fair Rubrics
	7.3 Minimize threats and distractions	Interest Surveys 1&2, Fair Posttreatment Interview, Unit Posttreatment Interview

	8.2 Vary demands and resources to optimize challenge	Application Cards, Human Tableau, S&E Fair Rubrics
	8.3 Foster collaboration and community	Human Tableau
	8.4 Increase mastery-oriented feedback	
	9.1 Promote expectations and beliefs that optimize motivation	
	9.2 Facilitate personal coping skills and strategies	
	9.3 Develop self-assessment and reflection	

Data Collection and Analysis Strategies

Cell Structure and Function Pretest/Posttest

The Cell Structure and Function Pretest and Posttest measured student content knowledge for this unit and aligned with Middle School Life Science Next Generation Science Standards (Appendix B). These tests addressed the UDL Principle of Action and Expression. The exam for this unit was adapted with permission from Ms. Stephanie Elkowitz, a content creator on the website Teachers Pay Teachers. It was further adapted and modified to meet UDL checkpoints and students' IEP accommodations.

The multiple-choice portion addressed the first aspect of the focus question: did the students learn new content? The short answer portion addressed the second aspect of the focus question: could the students apply content in new ways? This instrument, administered at the beginning and end of the unit, served as a norming tool to compare treatment and non-treatment groups. Results were analyzed using the Wilcoxon signed rank test and modeled with box and whisker plots.

Interest Survey 1

The Interest Survey 1 gauged students' changing attitudes towards inquiry, adoption of scientific attitudes, and enjoyment of science lessons and whether these metrics changed following a unit of instruction (Appendix C). While not directly measuring the focus question, students provided reflections on their feelings about inquiry and their scientific attitudes, one of which is the focus question-applying ideas in new ways. The Interest Survey also addressed UDL's Principle of Engagement. Administered at the beginning and the end of the Cell Structure and Function Unit, Interest Survey 1 used questions from the TOSRA, which served as a norming instrument to compare treatment and non-treatment groups. Results were subjected to simple statistical analyses, including mean and median, and visualized via bar graphs.

Application Cards

The Application Cards provided weekly insight into the focus question – students' ability to apply ideas in new ways (Appendix D). As a formative assessment, this activity addressed the UDL Principle of Action and Expression. It addressed the UDL Principle of Engagement because it asked students to think creatively about applications of new content, creating relevant and innovative projects that piqued their interest. Following a brainstorm of concepts covered during the week, students selected one topic and sketched an outline of a potential science fair project or engineering fair project.

Human Tableau Activity & Rubric

The Human Tableau Activity & Rubric allowed students to represent structures and functions through physical movement, thus addressing the focus question – applying ideas in new ways – and the UDL Principle of Action and Expression (Appendix E). It was aligned with Middle School Life Science Next Generation Science Standards. The rubric for the assessment was first introduced following the pretest so student could begin imagining ways to perform, for example, how a cell membrane separates external and internal environments or the interaction between the heart and lungs during a breath cycle. They had three class sessions to prepare. Following the presentation, students received a score based upon this rubric.

Unit Posttreatment Interview

The Unit Posttreatment Interviews sought further insight into students' experience with content and how they were asked to act on or express their understanding of it (Appendix F). The reflective nature of the interviews correlates with the focus question-applying ideas in new ways. They also addressed all three UDL Principles: Representation, Action and Expression, and Engagement. It asked them to reflect on how the content was taught and on how they were asked to show their growth. Additionally, because the interviews asked students' opinion and feelings, the principle of engagement is addressed. Students completed the interviews in class following the summative Posttest and interest surveys. Themes that arose from this subjective data were presented as commentary and used as evidence to make conclusions and propose new directions to take this study.

Organization of the Body Pretest/Posttest

The Organization of the Body Pretest and Posttest measured student content knowledge for this unit and aligned with Middle School Life Science Next Generation Science Standards (Appendix G). These tests addressed the UDL Principle of Action and Expression. The exam for this unit was adapted with permission from Ms. Stephanie Elkowitz, a content creator on the website Teachers Pay Teachers. It was further adapted and modified to meet UDL checkpoints and students' IEP accommodations.

The multiple-choice portion addressed the first aspect of the focus question: did the students learn new content? The short answer portion addressed the second aspect of the focus question: could the students apply content in new ways? This instrument, administered at the beginning and end of the unit, served as a norming tool to compare treatment and non-treatment groups. Results were analyzed using the Wilcoxon signed rank test and modeled with box and whisker plots.

Interest Survey 2

The Interest Survey 2 gauged students' changing attitudes towards inquiry, adoption of scientific attitudes, and enjoyment of science lessons and whether these metrics changed following a unit of instruction (Appendix H). While not directly measuring the focus question, students provided reflections on their feelings about inquiry and their scientific attitudes, one of which is the focus question-applying ideas in new ways. The Interest Survey also addressed UDL's Principle of Engagement. Administered at the beginning and the end of the Organization of the Body Unit, Interest Survey 2 used questions from the TOSRA, which served as a norming instrument to compare treatment and non-treatment groups.

S&E Fair: Science Rubric

The S&E Fair: Science Rubric was the marking instrument for students who completed a science project in the March Science & Engineering Fair (Appendix I). The rubric was created using the web application RubiStar and was modified for this year's fair. Science fair projects addressed the Science and Engineering Practices of Next Generation Science Standards. Science fair projects aligned precisely with the focus of this study - applying ideas in new ways. As a form of assessment, these projects addressed the UDL Principle of Action and Expression.

Because the students selected a project interesting to them, these projects addressed the Principle of Engagement.

Students practiced the scientific method throughout school year 2022-2023. They were informed of the option to complete a science project following an experimental design of their own creation, or an engineering project following the design cycle. Students wrote proposals outside of class. These proposals included introduction, materials, methods, and experimental design, and students received review and support as needed. Following approval of proposals, students received in-class, scaffolded instruction in data analysis and conclusion writing. Posters were created in-class following a model poster. Students presented their posters and projects at the S&E Fair. Students who took the science fair option were assessed by this rubric.

S&E Fair: Engineering Rubric

The S&E Fair: Engineering Rubric was the marking instrument for students who completed an engineering project in the March Science & Engineering Fair (Appendix J). The rubric was created using the web application RubiStar and was modified for this year's fair. Engineering fair projects addressed the Science and Engineering Practices of Next Generation Science Standards. These projects aligned precisely with the focus of this study - applying ideas in new ways. As a form of assessment, these projects addressed the UDL Principle of Action and Expression. Because the students selected a project interesting to them, these projects addressed the Principle of Engagement.

They were informed of the option to complete a science project following an experimental design of their own creation, or an engineering project following the design cycle. Students wrote proposals, which included their ideas and compared them to similar ideas, a prototype design with variables to improve, and methods for testing. These were written outside of class with teacher-support as needed. Following approval of proposals, students received in-class, scaffolded instruction in data analysis and conclusion writing. Posters were created in-class following a model poster. Students presented their posters and projects at the S&E Fair. Students who took the engineering fair option were assessed by this rubric.

Fair Posttreatment Interview

The Fair Posttreatment Interview sought further insight into students' experience with S&E Fair (Appendix K). Interview questions alluded to the focus question by asking what academic strengths they were highlighted through their project and what skills they gained. It addressed all three UDL Principles: Representation, Action and Expression, and Engagement. It asked them to reflect on how the scientific method and engineering design process was taught and on how they were asked to show their growth at the fair. Because the interviews asked students' opinion and feelings, the principle of engagement was addressed. Students took the posttreatment interview in class. Themes that arose from this subjective data were presented as commentary and used as evidence to make conclusions and propose new directions to take this study.

Triangulation Matrix

Focus Question: How do the Universal Design for Learning principles affect students' ability to apply ideas in new ways?

Sub-question 1: Did the students learn new content?

Sub-question 2: Could they apply it in new ways? (Table X)

Table X. Data Triangulation Matrix

Instrument	Did They Learn?	Could They Apply?
MC Pretest/Posttest	X	
MC Posttest Revisions	X	X
SA Pretest/Posttest	X	X
SA Posttest Revision	X	X
Application Cards	X	X
Human Tableau	X	X
Interest Survey 1&2	X	X
Unit Posttreatment Interview	X	X
S&E Fair Rubrics	X	X
Fair Posttreatment Interview	X	X

DATA ANALYSIS

Claim 1: Universal Design for Learning promotes students' learning of new content.

In the first treatment, Grade 7 (G7) served as the treatment group, and Grade 8 (G8) as the nontreatment group. The multiple-choice portion of the Cell Structure and Function Unit Exam served as the norming tool to gauge students' learning of new content. Students' pretest and posttest scores were converted to normative gains (<g>) (Hake, 1998). The mean and median provide perspective on the data, but overall, with a *p*-value of 0.20, differences in learning gains are outside of the 5% significance level, and do not support this claim. The normative gains for students with special educational needs (SEN) were compared with their classes' overall normative gains. When the treatment group SEN students' normative gains were compared to the treatment group overall, the *p*-value was less than 0.001 and was statistically significant. When the nontreatment SEN students' normative gains were compared to the nontreatment group overall, the *p*-value was less than 0.001 and these results were also statistically significant (Table 6) (Figure 5).

Table 6. Mean and median normative gains on multiple-choice portion of Treatment 1: Cell Structure and Function Unit. *p*-values compare treatment to the nontreatment groups, but students with special educational needs (SEN) are compared to their class. Treatment (N = 13), Nontreatment (*N*=15), Treatment SEN (*N*=6), Nontreatment SEN (*N*=6).

	Treatment	Nontreatment	Treatment SEN	Nontreatment SEN
Mean	0.35	0.23	0.56	0.29
Median	0.32	0.24	0.59	0.24
p-value	0.20		4.60E-28	4.51E-36
Null	Failed to Reject		Reject	Reject

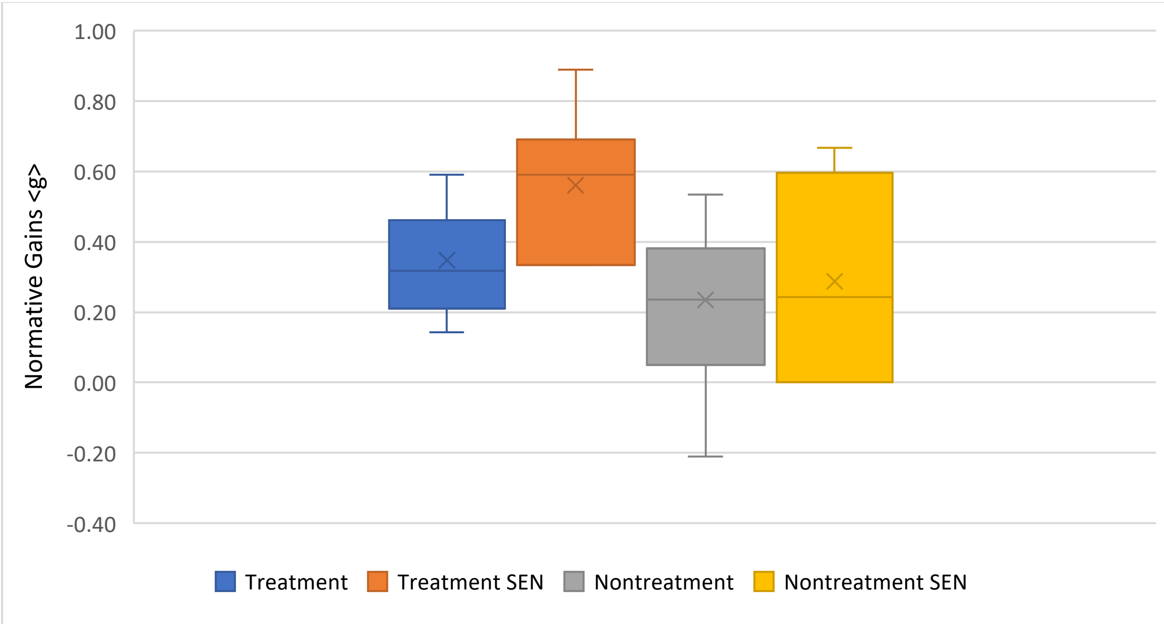

Figure 5. Note: Box and whiskers diagram shows normative gains on multiple choice portion of Treatment 1: Cell Structure and Function. Normative gains of treatment and nontreatment groups are shown, and the SEN students in each group. Treatment (*N* = 13), Nontreatment (*N*=15), Treatment SEN (*N*=6), Nontreatment SEN (*N*=6).

Students provided perspective on their experience of each unit in two ways: they were interviewed individually and then as a group. For Treatment 1: Cell Structure and Function, during the individual interviews, they described what they found most memorable, most useful, then reflected on how they might apply the content in the future, and whether their perception of science had changed following the unit. These were coded at the researcher's discretion (Table 7) (Table 8) (Figure 6) (Figure 7) (Figure 8) (Figure 9) (Figure 10) (Figure 11) (Figure 12).

The treatment group indicated that their perception of science had changed because, as one student commented, "I now understand why I have to drink water."

Table 7. For Treatment 1: Cell Structure and Function, students' responses to the individual interviews were coded and tallied. Treatment, or Tx (N=13), Nontreatment, or NonTx (N=15).

Most Memorable	All	Tx	NonTx
Content	7	2	5
Kingdom Project	7	3	4
Human Tableau	4	4	0
Jeopardy	2	1	1
N/A	5	2	3
Most Useful	All	Tx	NonTx
Content	9	3	6
Kingdom Project	2	1	1
N/A	12	5	7
Application of Content	All	Tx	NonTx
Career	4	2	2
Practical Use	4	2	2
N/A	20	9	11
Change Perception of Science	All	Tx	NonTx
Yes	9	7	2
No	16	5	11

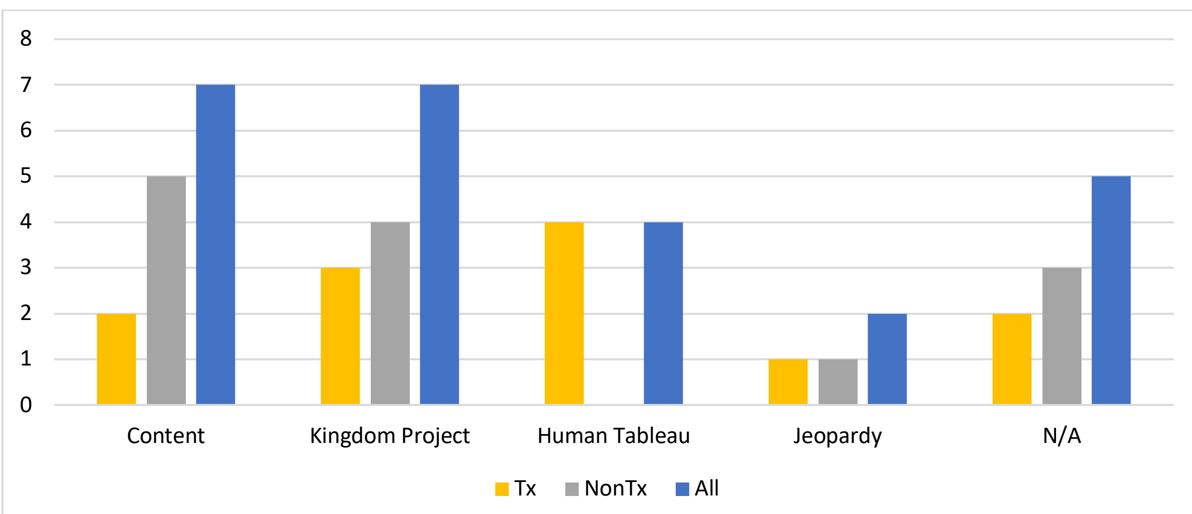

Figure 6. Students' responses to the individual interview question about which activities were most memorable in Treatment 1: Cell Structure and Function. Treatment, or Tx (N=13), Nontreatment, or NonTx (N=15).

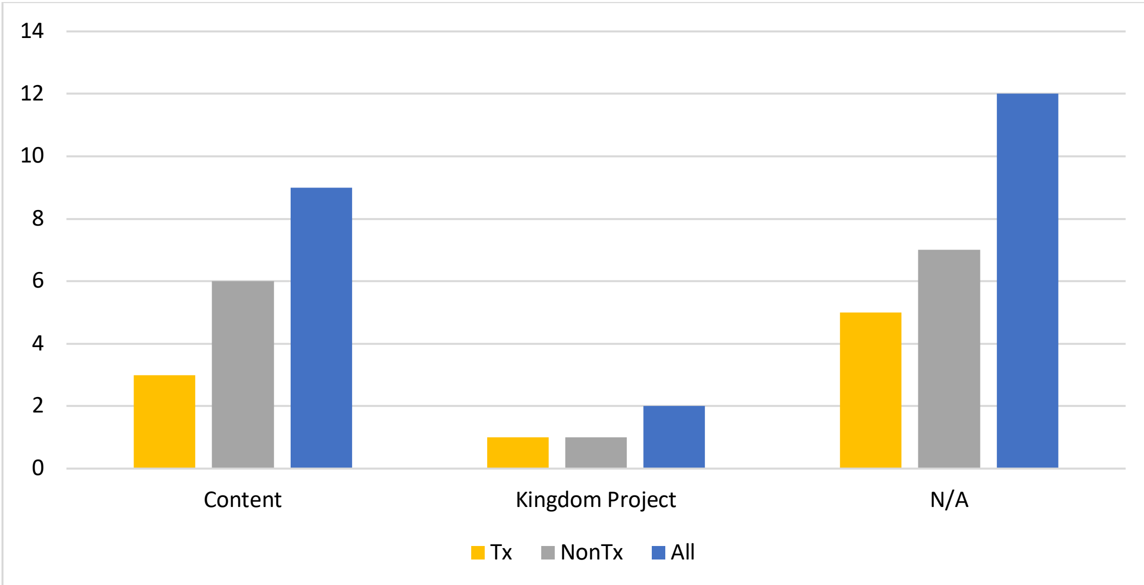

Figure 7. Students' responses to the individual interview question about which activities were most useful in Treatment 1: Cell Structure and Function. Treatment, or Tx (*N*=13), Nontreatment, or NonTx (*N*=15).

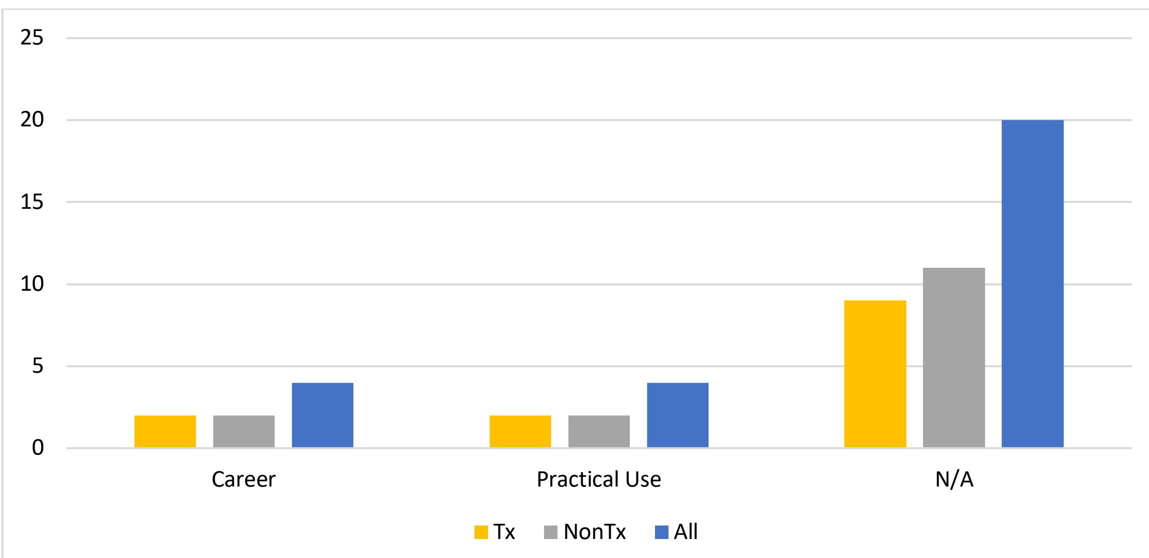

Figure 8. Students' responses to the individual interview question about how they could use the content from Treatment 1: Cell Structure and Function in their lives. Treatment, or Tx (*N*=13), Nontreatment, or NonTx (*N*=15).

Table 8. Interviewed as a group, students provided the following feedback on their experience in Treatment 1: Cell Structure and Function. Treatment, or Tx (N=13), Nontreatment, or NonTx (N=15).

Content Presentation, Positive	All	Tx	NonTx
Collaboration	7	0	7
Human Tableau	6	6	0
Jeopardy	6	6	0
Student Presentations	6	0	6
Teacher Examples	5	0	5
Teacher Presentations	2	0	2
Kingdom Project	3	3	0
Content Presentation, Negative	**All**	**Tx**	**NonTx**
Packet Work	15	12	13
Lab Notebook	13	0	13
Jeopardy Chaotic	6	6	0
Kingdom Project	7	7	9
Lots of Activity	9	9	0
Study Guide Format	8	8	0
Assessment, Positive	**All**	**Tx**	**NonTx**
Multiple Choice	18	6	12
Teacher Explanations	12	0	12
Formative Assessments	6	6	0
Relevancy	5	5	0
Time Allotted	5	0	5
Assessment, Negative	**All**	**Tx**	**NonTx**
Short Answers	24	11	13
Studying	13	0	13
Study Guide Format	13	0	13
Chem of Chocolate	10	10	0
Due Dates	8	0	8
Lab Notebook Marking	2	0	2
Taking Exams	8	8	0
Change Perception of Science	**All**	**Tx**	**NonTx**
Yes	20	11	9
No	8	6	2

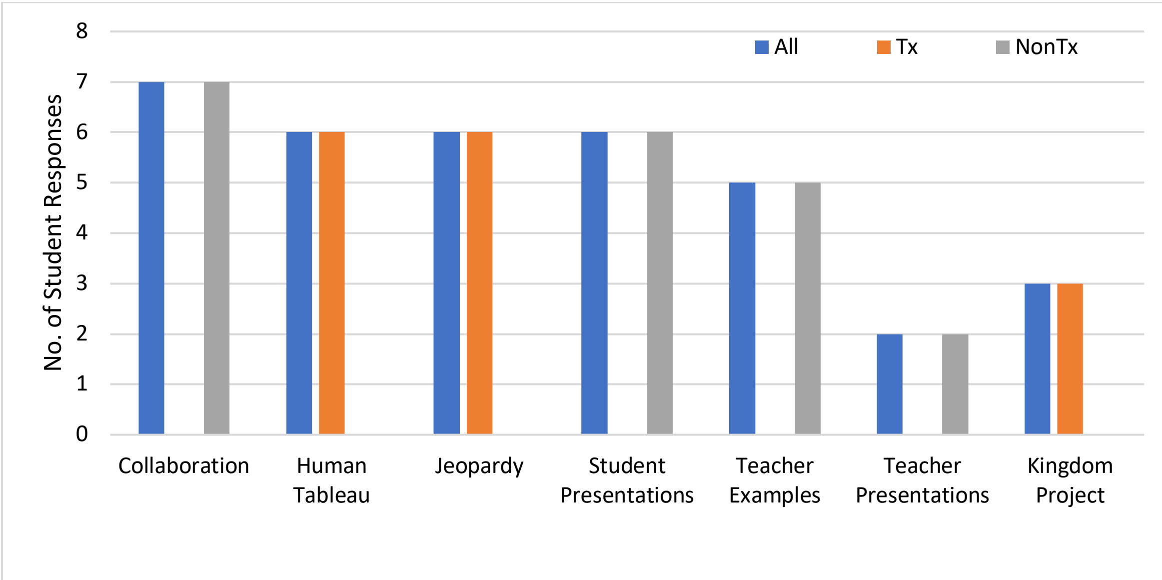

Figure 9. Interviewed as a group, students identified the activities they enjoyed in the presentation of content for Treatment 1: Cell Structure and Function. Treatment, or Tx (*N*=13), Nontreatment, or NonTx (*N*=15).

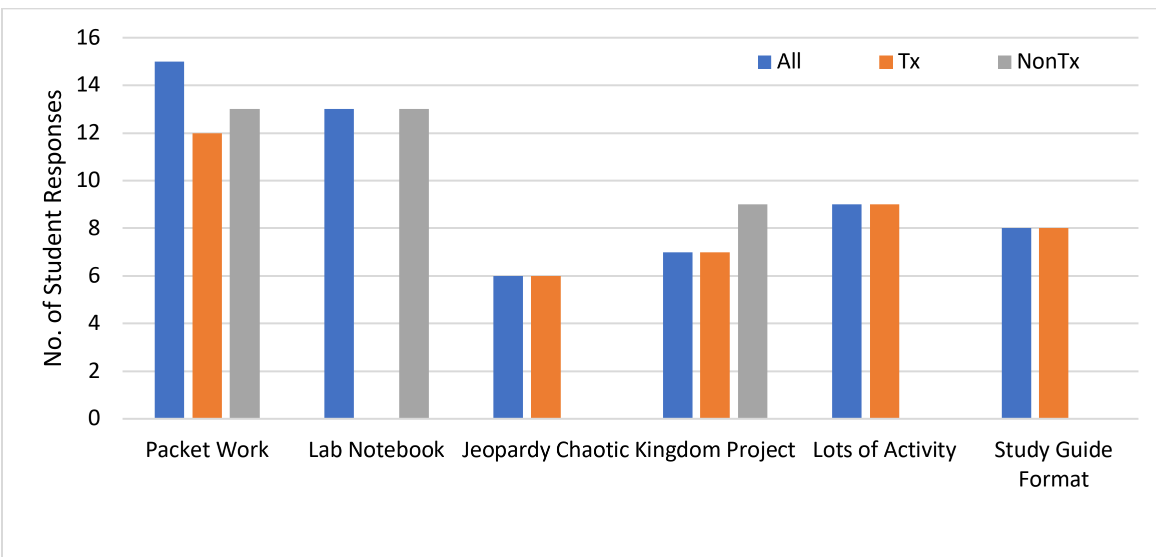

Figure 10. Interviewed as a group, students identified the activities they did not enjoy in the presentation of content for Treatment 1: Cell Structure and Function. Treatment, or Tx (*N*=13), Nontreatment, or NonTx (*N*=15).

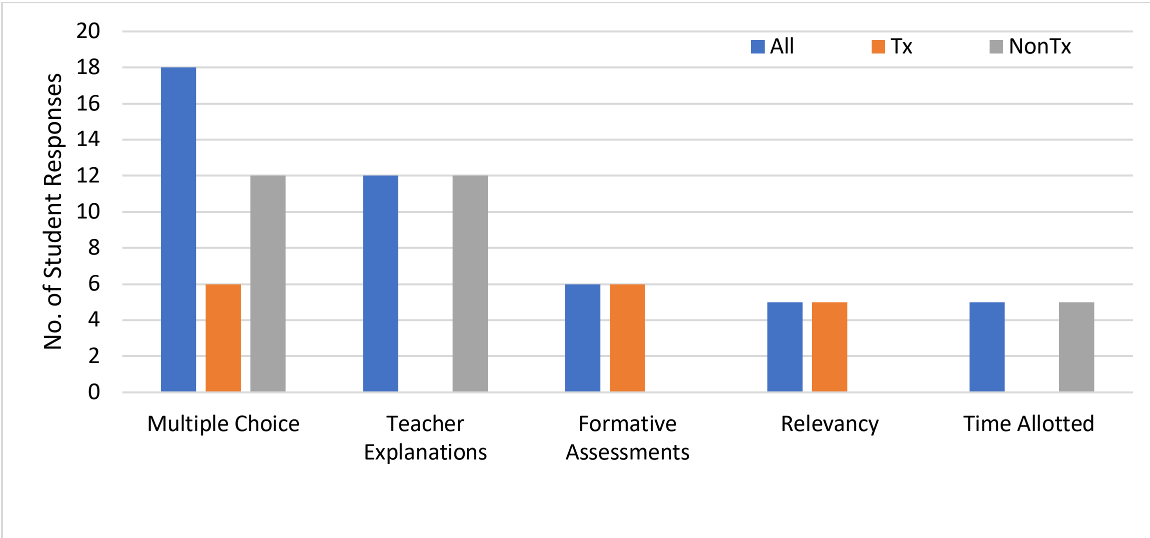

Figure 11. Interviewed as a group, students identified the aspects of assessments they enjoyed throughout Treatment 1: Cell Structure and Function. Treatment, or Tx (*N*=13), Nontreatment, or NonTx (*N*=15).

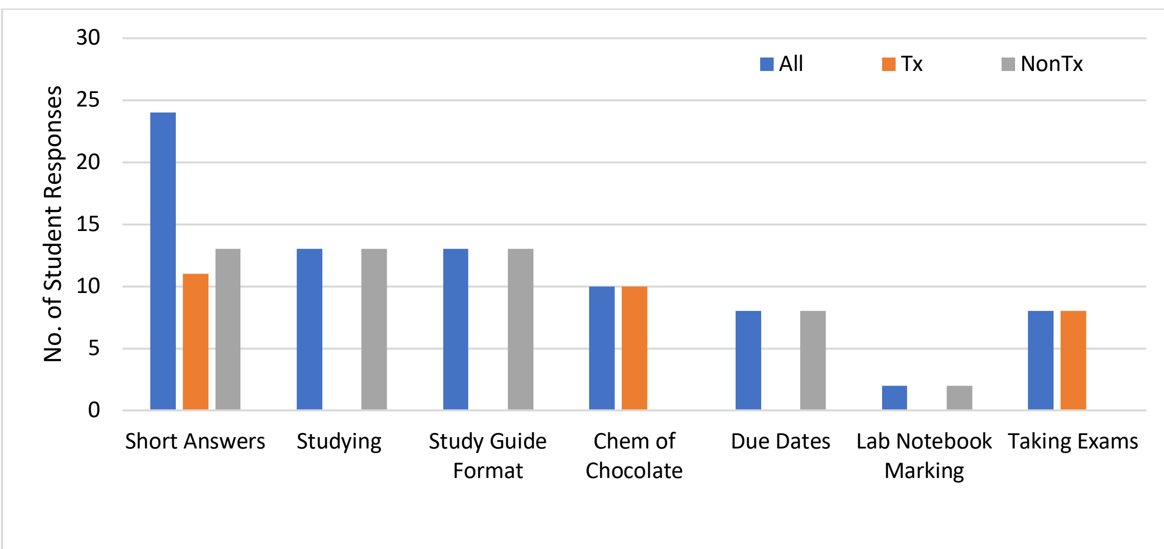

Figure 12. Interviewed as a group, students identified the aspects of assessments they did not enjoy throughout Treatment 1: Cell Structure and Function. Treatment, or Tx (*N*=13), Nontreatment, or NonTx (*N*=15).

In the second treatment, Grade 8 (G8) served as the treatment group, and Grade 7 (G7) as the nontreatment group. The multiple-choice portion of the Organization of the Body Unit Exam served as the norming tool to gauge students' learning of new content. Students' pretest and posttest scores were converted to normative gains (<g>) (Hake, 1998). The mean and median provide perspective on the data, but overall, with a *p*-value of 0.40, differences in learning gains are outside of the 5% significance level, and do not support this claim (Table 9) (Figure 13). The normative gains for students with special educational needs (SEN) were compared with their classes' overall normative gains. When the treatment group SEN students' normative gains were compared to the treatment group overall, the *p*-value was less than 0.001 meaning their gains were statistically significant. When the nontreatment SEN students' normative gains were compared to the nontreatment group overall, the *p*-value was less than 0.001 and were also statistically significant.

Table 9. Mean and median normative gains on multiple-choice portion of Treatment 2: Organization of the Body Unit. *p*-values compare treatment to the nontreatment groups, but students with special educational needs (SEN) are compared to their class. Treatment (N = 13), Nontreatment (N=15), Treatment SEN (N=6), Nontreatment SEN (N=6).

	Treatment	Nontreatment	Treatment SEN	Nontreatment SEN
Mean	0.52	0.40	0.41	0.37
Median	0.53	0.46	0.35	0.31
p-value	0.40		7.90E-36	1.79E-28
Null	Failed to Reject		Reject Null	Reject Null

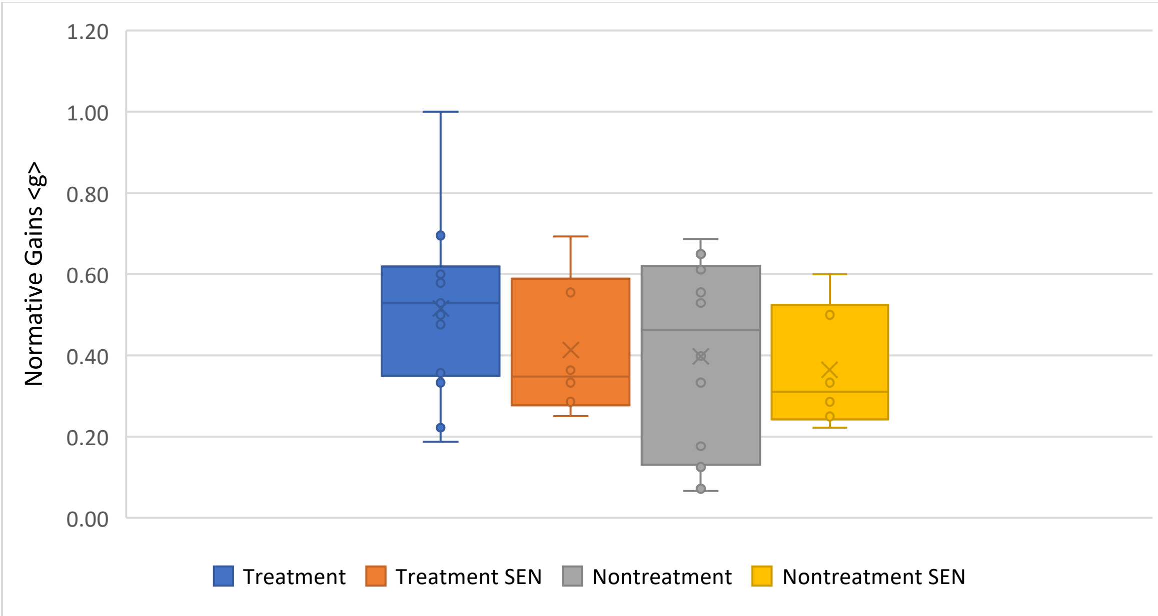

Figure 13. Box and whiskers diagram shows normative gains on multiple choice portion of Treatment 2: Organization of the Body. Normative gains of treatment and nontreatment groups are shown, and the SEN students in each group. Treatment (*N*=13), Nontreatment (*N*=15), Treatment SEN (*N*=6), Nontreatment SEN (*N*=6).

Students provided perspective on their experience of each unit in two ways: first they were interviewed individually and then as a group. For Treatment 2: Organization of the Body, during the individual interviews, they described what they found most memorable, most useful, then reflected on how they might apply the content in the future, and whether their perception of science had changed following the unit. These were coded at the researcher's discretion (Table 10) (Table 11) (Figure 14) (Figure 15) (Figure 16) (Figure 18) (Figure 19) (Figure 20). One member of the treatment group indicated that their perception of science had changed because "I now know I can calm myself quickly if I ever am very stressed," referencing the blood pressure/meditation lab we did as part of the unit.

Table 10. For Treatment 2: Organization of the Body, students' responses to the individual interviews were coded and tallied. Treatment, or Tx (N=15), Nontreatment, or NonTx (N=13).

Most Memorable	All	Tx	NonTx
Content	13	4	9
Lab	5	5	0
Human Tableau	3	3	0
Exam	2	1	1
N/A	5	2	3
Most Useful	All	Tx	NonTx
Content	15	7	8
Lab	2	2	0
Exam	1	0	1
Presentations	1	1	0
N/A	9	5	4
Use of Content	All	Tx	NonTx
N/A	17	11	6
Career	8	3	5
Practical Use	3	1	2
Change Perception of Science	All	Tx	NonTx
Yes	5	0	5
No	23	15	8

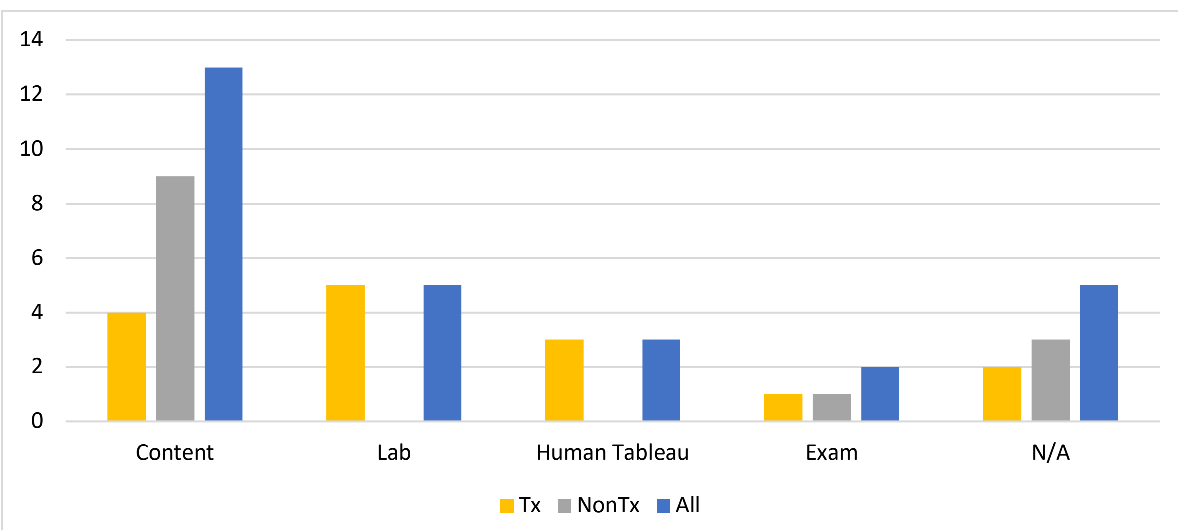

Figure 14. Students' responses to the individual interview question about which activities were most memorable in Treatment 2: Organization of the Body. Treatment, or Tx (N=15), Nontreatment, or NonTx (N=13).

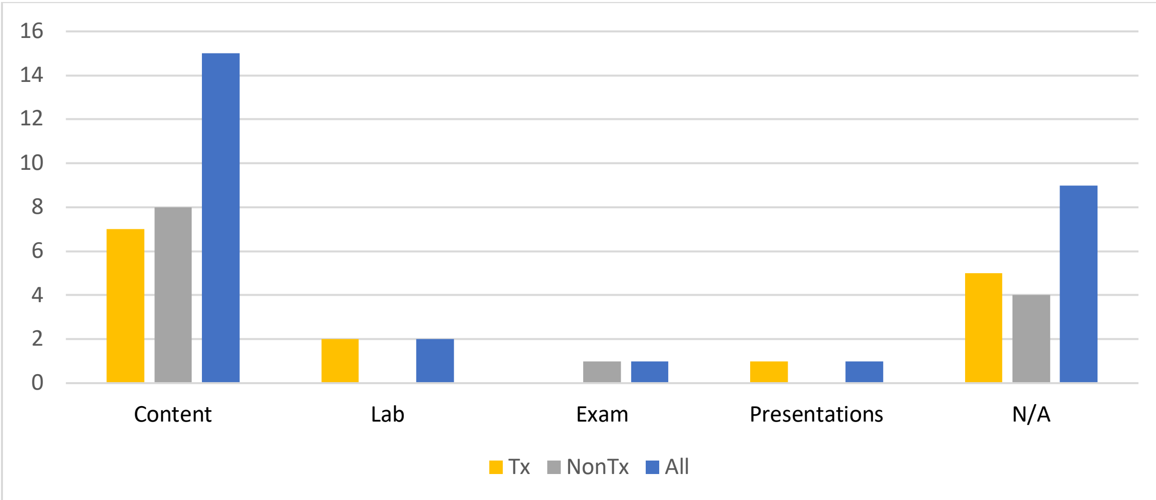

Figure 15. Students' responses to the individual interview question about which activities were most useful in Treatment 2: Organization of the Body. Treatment, or Tx (*N*=15), Nontreatment, or NonTx (*N*=13).

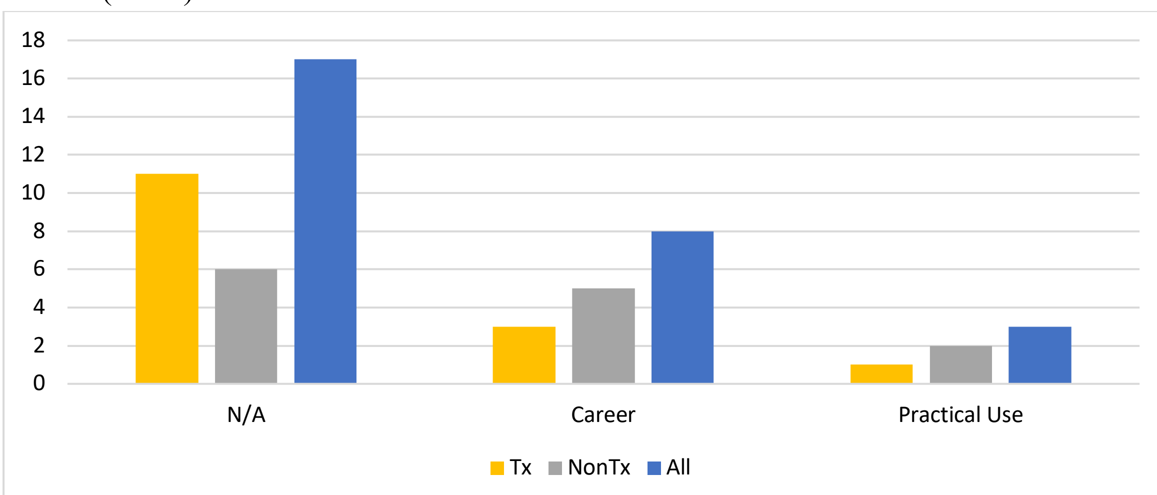

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Figure 16. Students' responses to the individual interview question about how they could use the content from Treatment 2: Organization of the Body. Treatment, or Tx (*N*=15), Nontreatment, or NonTx (*N*=13).

Table 11. For Treatment 2: Organization of the Body, students' responses to the group interviews were coded and tallied. Treatment, or Tx (*N*=15), Nontreatment, or NonTx (*N*=13).

Content Presentation, Positive	All	Tx	NonTx
No Lab Notebook	15	15	0
No Packets	13	13	0
Exam Revision	13	0	13
Packet Work	13	0	13
Study Guide	7	0	7
Shorter Lessons	7	0	7
Organized	4	0	4
No Classwork	1	1	0
Content Presentation, Negative	**All**	**Tx**	**NonTx**
Disorganized	20	15	5
Study Guide Format	20	15	5
Amount of Content per Day	12	0	12
Insufficient Time to Study	8	0	8
Study Guide Content	6	6	0
Content Overload	5	0	5
Assessment, Positive	**All**	**Tx**	**NonTx**
Multiple Choice	28	15	13
Facts Only	15	15	0
Exam Revision	12	0	12
Short Answer Pre-Coaching	10	0	10
Revision: Explaining New Understanding	9	0	9
Assessment, Negative	**All**	**Tx**	**NonTx**
Short Answer	17	10	7
Studying	15	15	0
Confusing Exam Questions	11	11	0
Exam Revision	7	0	7
Short Answer Valuation	5	0	5
Change View of Science	**All**	**Tx**	**NonTx**
Yes	6	0	6
No	18	15	3

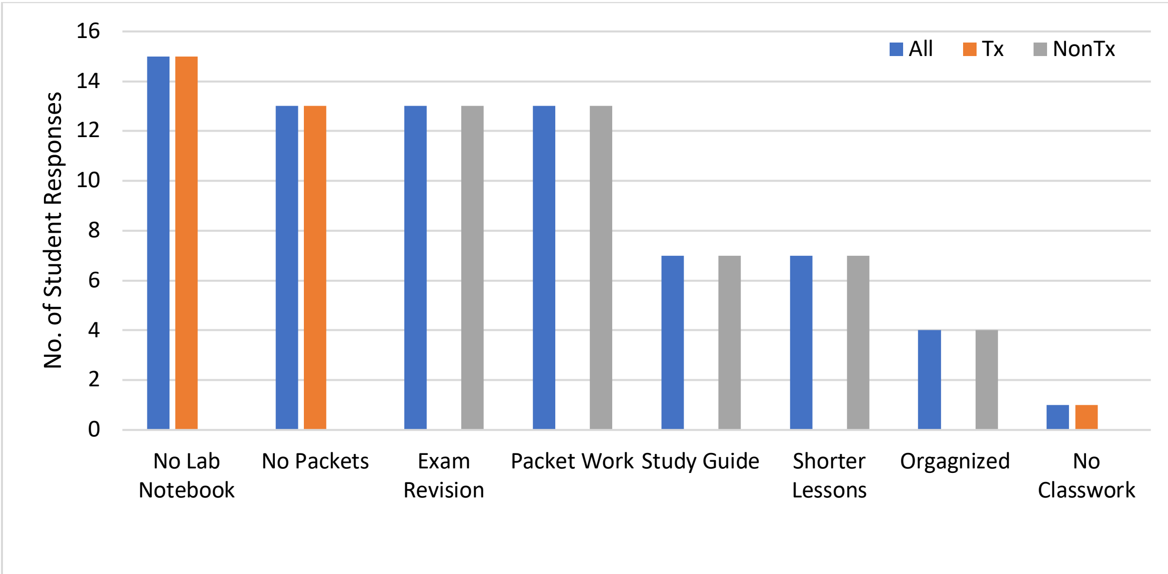

Figure 17. Interviewed as a group, students identified the activities they enjoyed in the presentation of content for Treatment 2: Organization of the Body. Treatment, or Tx (*N*=15), Nontreatment, or NonTx (*N*=13).

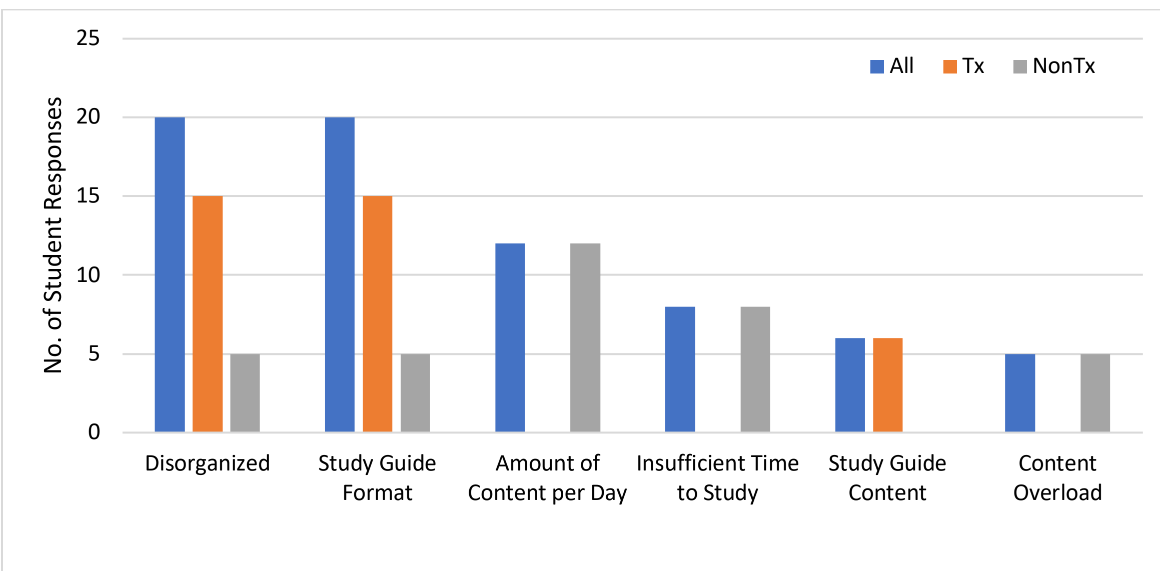

Figure 18. Interviewed as a group, students identified the activities they did not enjoy in the presentation of content for Treatment 2: Organization of the Body. Treatment, or Tx (*N*=15), Nontreatment, or NonTx (*N*=13).

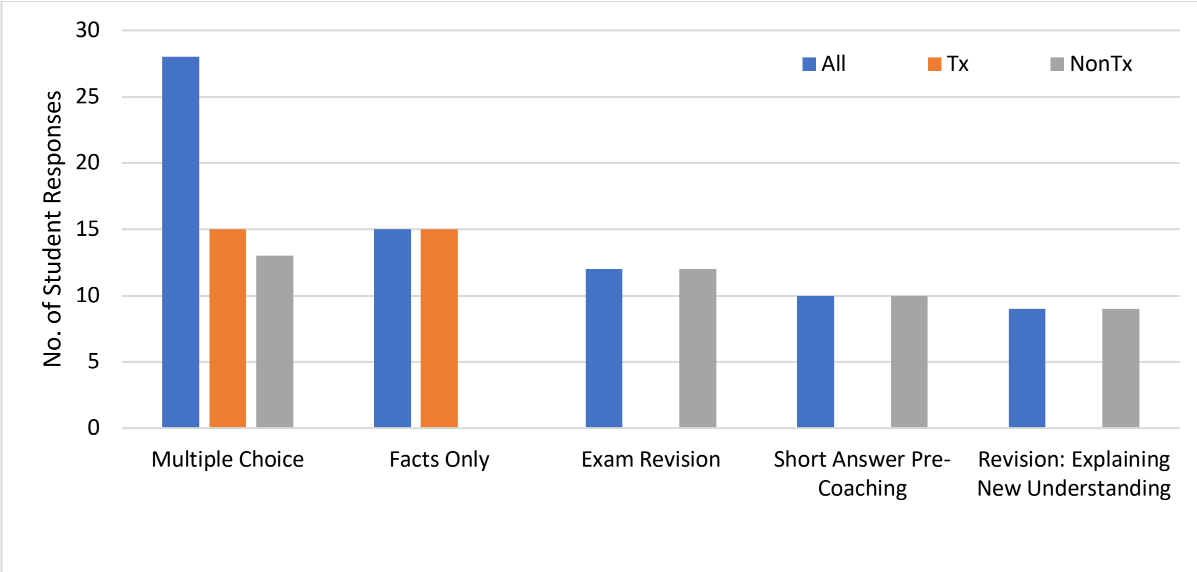

Figure 19. Interviewed as a group, students identified the aspects of assessments they enjoyed throughout Treatment 2: Organization of the Body. Treatment, or Tx (*N*=15), Nontreatment, or NonTx (*N*=13).

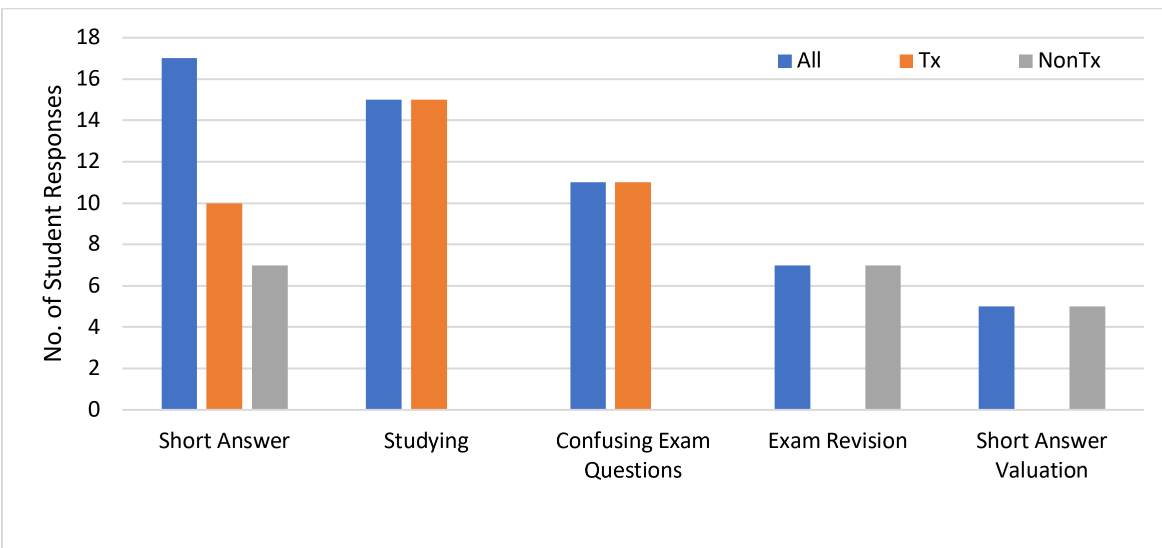

Figure 20. Interviewed as a group, students identified the aspects of assessments they did not enjoy throughout Treatment 2: Organization of the Body. Treatment, or Tx (*N*=15), Nontreatment, or NonTx (*N*=13).

In the third treatment, Science and Engineering Fair, students chose between a science project or an engineering project. For the students who chose to do a science project, they were marked using the Science Project Rubric. Mean scores were calculated for four groups: G7, G8, and the sub-group of SEN students for each grade (Table 12). Mean scores on the key concepts of interest were summarized: creation of an idea, development of a hypothesis, identification of independent and dependent variables, identification of relevant constants, and selection of a relevant control (Figure 21).

Table 12. Mean scores by class and by subgroup for key concepts on the Science Project Rubric.

	No. of Projects	Idea	Hypothesis	Variables	Constants	Control
Grade 7	5	4.0	4.0	3.4	3.4	3.8
Grade 8	12	3.8	3.3	3.4	3.5	3.5
Grade 7 SEN	4	4.0	4.0	3.3	3.3	3.8
Grade 8 SEN	5	4.0	4.0	3.2	3.6	3.4

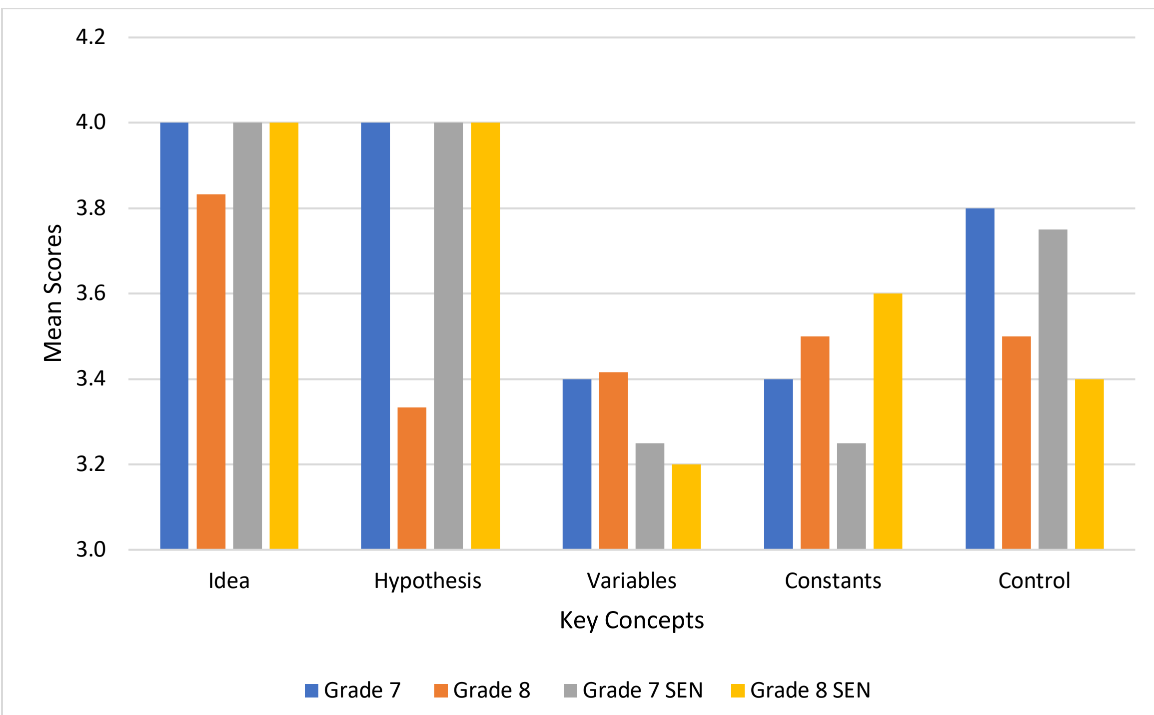

Figure 21. Mean scores on key concepts for science projects, as marked by the Science Project Rubric, compared by group and sub-group. Grade 7 (*N*=5), Grade 8 (*N*=12), Grade 7 SEN (*N*=4), Grade 8 SEN (*N*=5).

In the third treatment, Science and Engineering Fair, students chose between a science project or an engineering project. For the students who chose to do an engineering project, they were marked using the Engineering Project Rubric. Mean scores were calculated for four groups: G7, G8, and the sub-group of SEN students for each grade (Table 13). Mean scores on the key concepts of interest were summarized: creation of an idea, development of a prototype, identification of important variables, comparison to alternate ideas, and argumentation for the selected prototype (Figure 22).

Table 13. Mean scores on key concepts for engineering projects, as marked by Engineering Project Rubric, compared by group and sub-group.

	No. of Projects	Idea	Development	Variables	Alternates	Solution
Grade 7	8	3.8	3.6	3.8	3.6	3.3
Grade 8	3	3.3	3.7	3.7	3.7	3.7
Grade 7 SEN	2	4.0	4.0	4.0	4.0	3.5
Grade 8 SEN	1	4.0	4.0	4.0	4.0	4.0

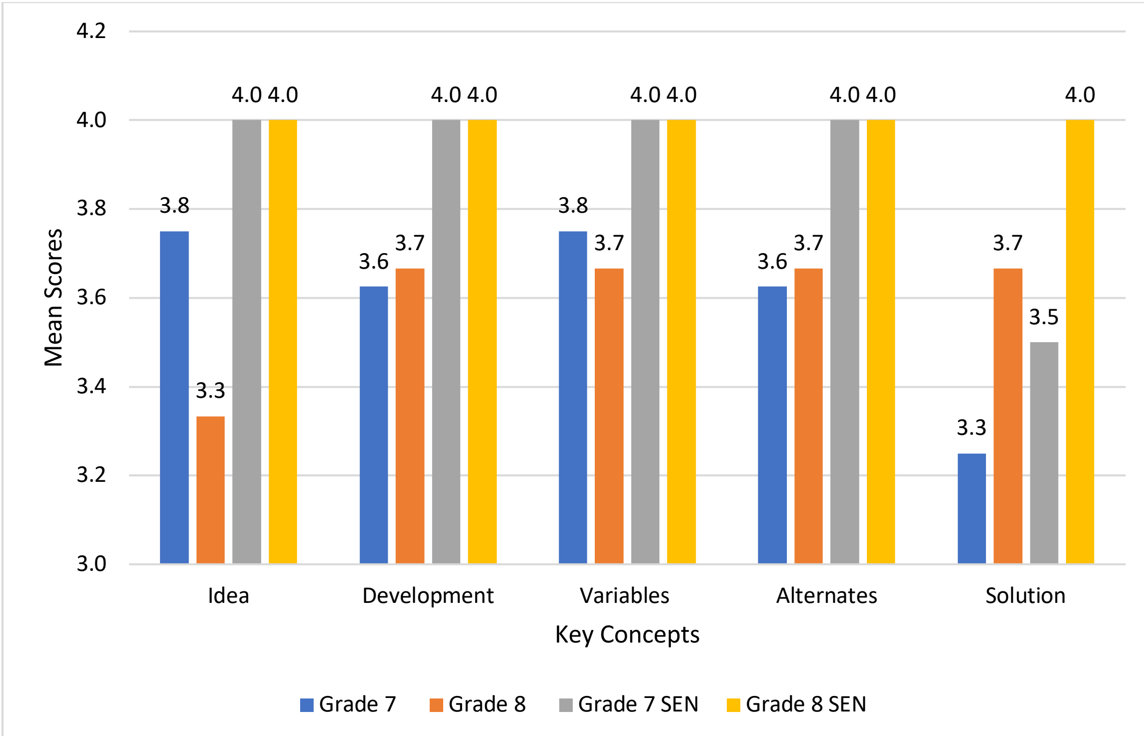

Figure 22. Mean scores on key concepts for engineering projects, as marked by the Engineering Project Rubric, compared by group and sub-group. Grade 7 (*N*=8), Grade 8 (*N*=3), Grade 7 SEN (*N*=2), Grade 8 SEN (*N*=1).

In Treatment 3: Science and Engineering Fair, students participated in two interviews. All students completed an individual interview, but for the group interviews, only willing students participated. This resulted in four Grade 7 (G7) students participating and three Grade 8 (G8) students participating. Because of how the interviews were held, the group interviews were segregated by sex. In the female student group, one G7 SEN student and one G8 SEN student participated. In the male student group, two G7 SEN students participated. Students' responses to both the individual and group interviews were coded at the researcher's discretion (Table 14) (Table 15) (Table 16) (Table 17) (Figure 23) (Figure 24) (Figure 25) (Figure 26) (Figure 27) (Figure 28).

Table 14. For the individual interviews following the Science and Engineering Fair, the students responded to how this year's fair compared to last year's fair. Grade 7, or G7 (*N*=13), Grade 7 SEN, or G7 SEN (*N*=6), Grade 8, or G8 (*N*=15), and Grade 8 SEN, or G8 SEN (*N*=6).

	All	G7	G7 SEN	G8	G8 SEN
Less Time	11	6	5	5	1
More Interesting	4	2	1	2	1
More Difficult	4	1	1	3	1
Less Prepared	2	2	1	0	0
More Confusing	2	1	0	1	1
N/A	2	0	0	2	2

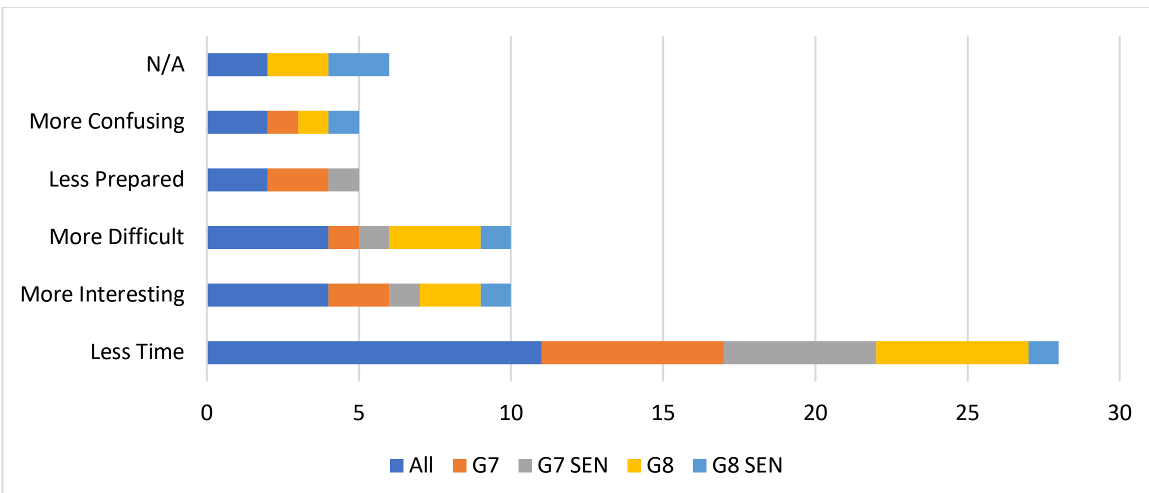

Figure 23. Student responses to the individual interview question, "How did this year's Science and Engineering Fair compare to last year's?" All (*N*=28), Grade 7, or G7 (*N*=13), Grade 7 SEN students, or G7 SEN (*N*=6), Grade 8, or G8 (*N*=15), and Grade 8 SEN students, or G8 SEN (*N*=6).

Table 15. For the individual interviews following the Science and Engineering Fair, the students reflected on the academic skills they developed most during the process. Grade 7, or G7 (*N*=13), Grade 7 SEN, or G7 SEN (*N*=6), Grade 8, or G8 (*N*=15), and Grade 8 SEN, or G8 SEN (*N*=6).

	All	G7	G7 SEN	G8	G8 SEN
N/A	9	3	2	6	4
Presenting	5	2	1	3	0
Researching	4	2	2	2	1
Personal Growth	3	3	0	3	0
Content	3	1	0	2	1
Writing	2	2	1	0	0

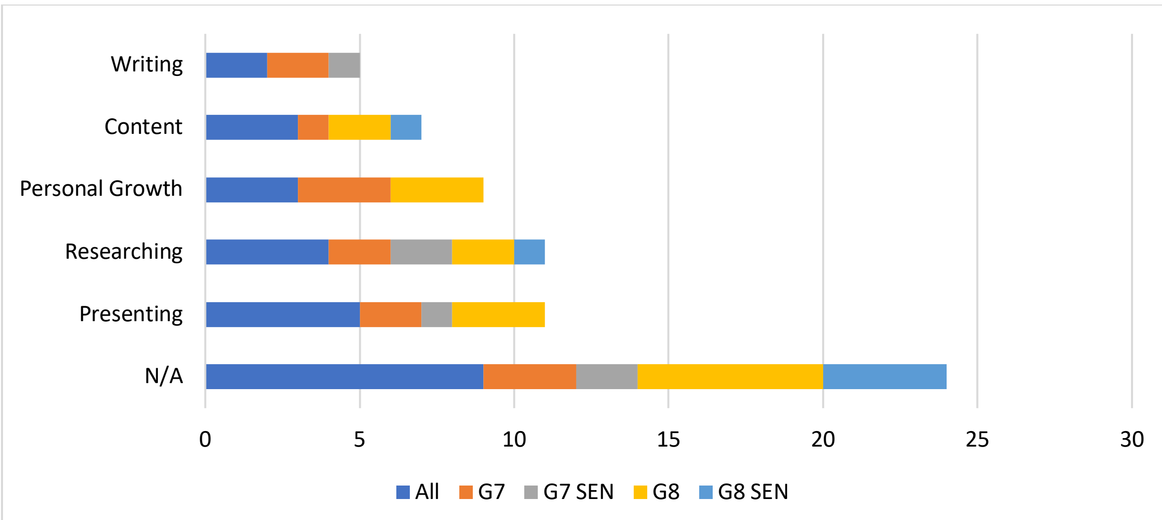

Figure 24. Student responses to the individual interview question asking which academic skills they strengthened through their project. All (*N*=28), Grade 7, or G7 (*N*=13), Grade 7 SEN students, or G7 SEN (*N*=6), Grade 8, or G8 (*N*=15), and Grade 8 SEN students, or G8 SEN (*N*=6).

Table 16. For the individual interviews following the Science and Engineering Fair, the students predicted how they could use the skills they developed through their projects in the future. Grade 7, or G7 (*N*=13), Grade 7 SEN, or G7 SEN (*N*=6), Grade 8, or G8 (*N*=15), and Grade 8 SEN, or G8 SEN (*N*=6).

	All	G7	G7 SEN	G8	G8 SEN
N/A	16	5	2	11	6
Content	7	5	3	2	0
Personal Growth	3	2	0	1	0
Researching	1	1	1	0	0
Writing	1	0	0	1	0

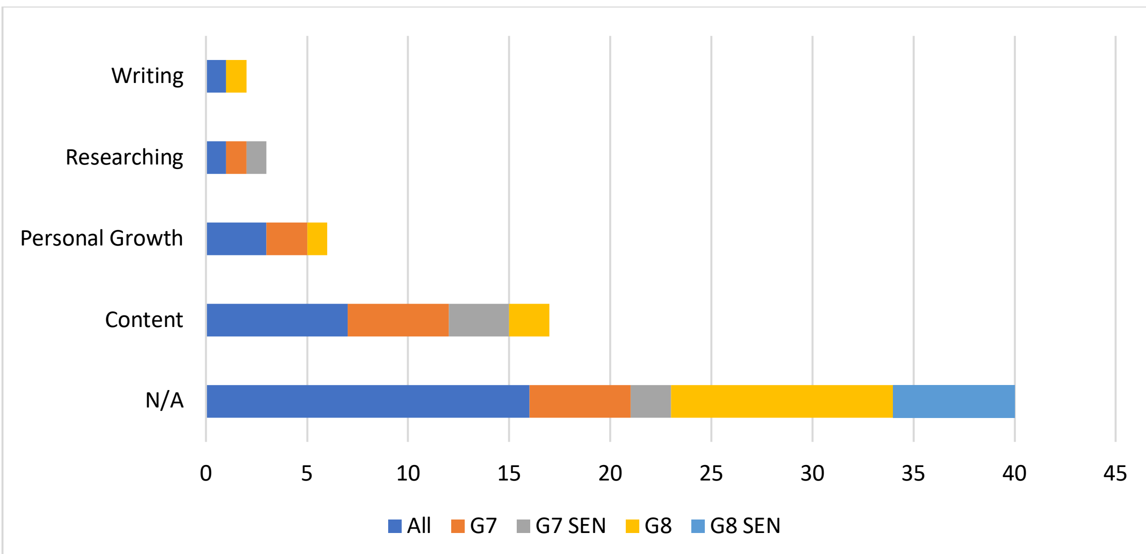

Figure 25. Student responses to the individual interview question asking how they could use the skills they developed through their projects in the future. All (*N*=28), Grade 7, or G7 (*N*=13), Grade 7 SEN students, or G7 SEN (*N*=6), Grade 8, or G8 (*N*=15), and Grade 8 SEN students, or G8 SEN (*N*=6).

Table 17. Group interviews following the Science and Engineering Fair provided feedback on the students' experience. G7 (*N*=4), G7 SEN (*N*=3), G8 (*N*=3), G8 SEN (*N*=1).

This Year Compared to Last Year	G7	G8
More Stressful	4	2
Less Time	4	2
"We don't like working at home."	4	3
Less Confusing	4	2
Better Communication	4	3
Academic Strengths Developed	**G7**	**G8**
Concept Retention	4	3
Stress Management	4	3
Focus	2	2
Persistence	2	1
Application of Skills	**G7**	**G8**
Newfound Creativity	4	1
Self-Awareness	1	1
Writing Essays	1	1
Problem Solving	0	1

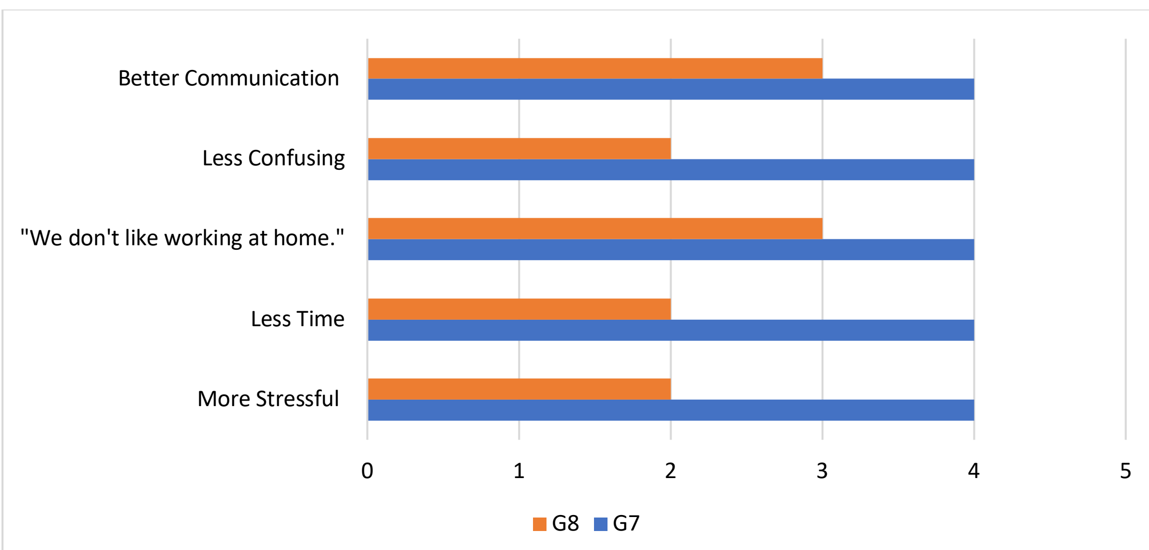

Figure 26. Student responses to the group interview question, "How did this year's Science and Engineering Fair compare to last year's?" Grade 7, or G7 (*N*=4), Grade 8, or G8 (*N*=3).

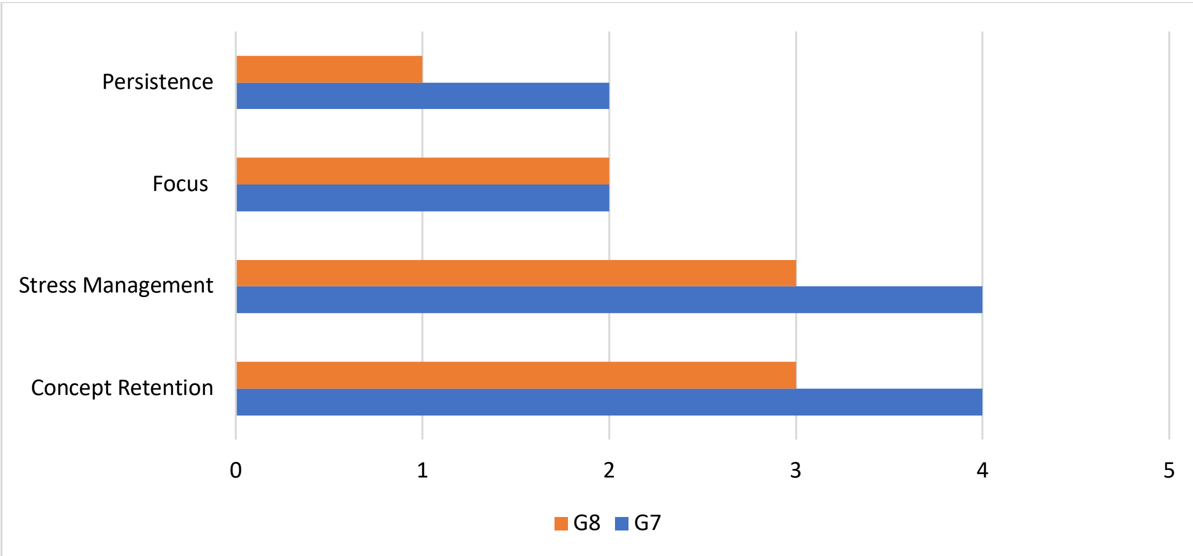

Figure 27. Students' responses during the group interview when asked which academic skills they developed most during the process of their Science and Engineering Fair project. Grade 7, or G7 (N=4), Grade 8, or G8 (N=3).

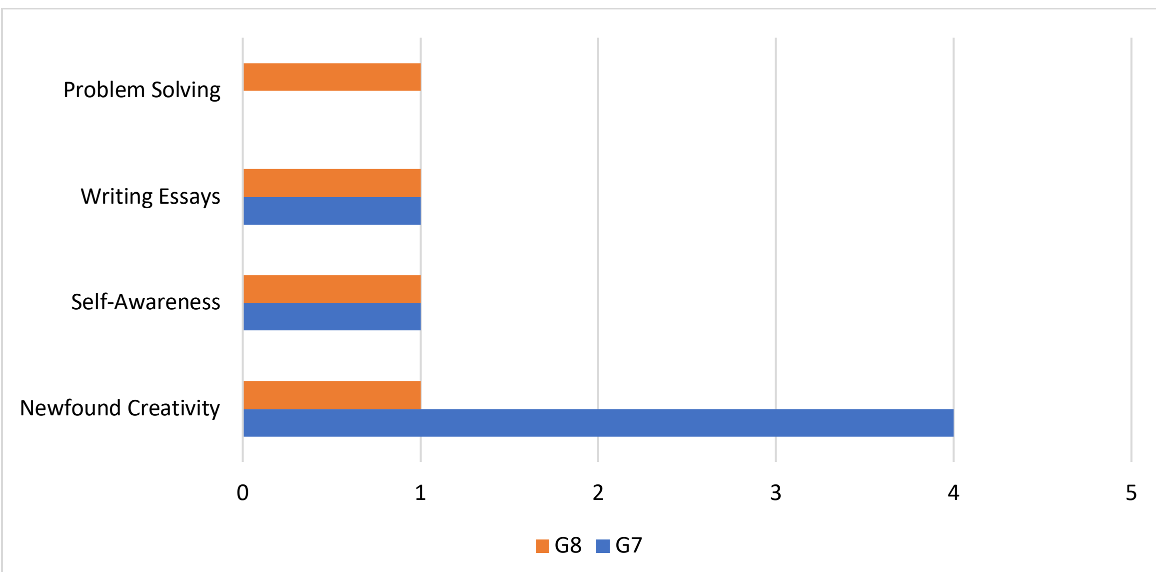

Figure 28. Students' responses during the group interview when asked how they could see themselves applying these skills developed during the project in their future. Responses coded by the researcher. Grade 7, or G7 (N=4), Grade 8, or G8 (N=3).

Students in both treatment and nontreatment groups provided feedback with respect to their scientific attitudes. These Likert-type assessments gave students a scale of 1-5 with 1 representing strongly disagree and 5 representing strongly agree. Overall, Wilcoxon rank sum for both Interest Survey 1 and Interest Survey 2 yielded *p*-values outside of the 5% significance level and thus, they could not be used as a norming tool. To derive some meaning from these data, a comparison of means by group and subgroup showed trends, even if not significant. Desired changes revolved around improving students' attitude towards inquiry, increasing their adoption of scientific attitudes, and increasing their enjoyment of science class. Green highlights indicate a trend towards the desired change. A star indicates a statement for which a low value represents the desired change. In Treatment 1, Grade 7 (G7) served as the treatment group and in Treatment 2, Grade 8 (G8) served as the treatment group (Table 18) (Table 19).

Table 18. For Interest Survey 1, general trends were sought from the mean difference of pretreatment surveys and posttreatment surveys. Green highlights indicate a desired change. A star identifies those questions for which a lower score represents the desired change. Treatment, or Tx (*N*=13), treatment SEN, or Tx SEN (*N*=6), nontreatment, or NonTx (*N*=15), nontreatment SEN, or NonTx SEN (*N*=6).

Attitude towards inquiry	Tx	Tx SEN	NonTx	NonTx SEN
*I would rather find out things by asking an expert than by doing an experiment.	0.17	0.80	0.12	0.80
I would rather solve a problem by doing an experiment than be told the answer.	0.25	0.20	-0.31	-0.60
*It is better to ask the teacher the answer than to find it out by doing experiments.	0.45	0.60	-0.26	0.05
Adoption of scientific attitudes				
*I find it boring to hear about new ideas.	0.12	0.40	-0.09	-0.20
In science experiments I like to use new methods which I have not used before.	-0.15	-0.20	-0.53	-1.80
*I am unwilling to change my ideas when evidence shows that the ideas are poor.	-0.45	-0.25	0.27	1.00
In science experiments, I report unexpected results as well as expected ones.	-0.64	-1.40	0.17	0.40
*I dislike listening to other people's opinions.	-0.27	0.00	-0.05	0.20
Enjoyment of science lessons				
Science is one of the most interesting school subjects.	-0.30	-0.40	-0.32	-0.35
*The material covered in science lessons is uninteresting.	0.17	0.80	0.19	-0.60
*I would enjoy school more if there were no science lessons.	0.17	0.83	0.69	0.25
I look forward to science lessons.	-0.17	-0.90	-0.77	-0.60

Table 19. For Interest Survey 2, general trends were sought from the mean difference of pretreatment surveys and posttreatment surveys. Green highlights indicate a desired change. A star identifies those questions for which a lower score represents the desired change. Question 8 was removed as a duplicate. Treatment, or Tx (*N*=15), treatment SEN, or Tx SEN (*N*=6), nontreatment, or NonTx (*N*=13), nontreatment SEN, or NonTx SEN (*N*=6).

Attitude towards inquiry	Tx	Tx SEN	NonTx	NonTx SEN
I would prefer to find out why something happens by doing an experiment rather than by being told.	-0.67	-0.33	0.15	-0.33
* I would rather agree with other people than do an experiment to find out for myself.	0.27	1.00	0.08	0.50
* It is better to be told scientific facts than to find them out from experiments.	0.53	1.17	-0.15	0.50
Adoption of scientific attitudes				
I enjoy reading about things which disagree with my previous ideas.	-0.13	0.33	-0.08	-0.33
* I dislike repeating experiments to check that I get the same results.	-0.47	0.33	0.09	0.17
I am curious about the world in which we live.	0.13	0.17	-0.08	0.00
* Finding out about new things is unimportant.	0.33	0.00	0.38	0.67
I like to listen to people whose opinions are different from mine.	-0.13	-0.50	0.38	0.67
Enjoyment of science lessons				
Science lessons are fun.	-0.26	0.17	0.23	0.33
School should have more science lessons each week.	0.00	-0.33	0.00	-0.17
* Science lessons are a waste of time.	-0.07	-0.17	0.62	0.50

Claim 2: UDL promotes students' ability to apply information in new ways.

Students completed exam revisions on the multiple-choice portion of the unit exam following the posttest. Exam revisions allowed students to use any modality to explain how their understanding changed after reviewing. In the first treatment, Grade 7 (G7) served as the treatment group, and Grade 8 (G8) as the nontreatment group. Students' pretest and revision scores were converted to normative gains (<g>) (Hake, 1998). The mean and median provide perspective on the data, and overall, with a *p*-value of 0.01, differences between treatment and nontreatment groups were significant at the 5% significance level (Table 20) (Figure 29). The normative gains for students with special educational needs (SEN) were compared with their classes' overall normative gains. When the treatment group SEN students' normative gains were compared to the treatment group overall, the *p*-value was less than 0.001. When the nontreatment SEN students' normative gains were compared to the nontreatment group overall, the *p*-value was less than 0.001. Treatment 1 multiple-choice revision scores support the claim that UDL promotes students' ability to apply information in new ways. SEN students' multiple-choice revision scores in both treatment and nontreatment group indicate that accommodations and modifications support their learning needs, but not necessarily that this treatment did.

Table 20: Mean and median normative gains on students' revision of multiple-choice portion of Treatment 1: Cell Structure and Function Unit. *p*-values compare treatment to the nontreatment groups, but students with special educational needs (SEN) are compared to their class. Treatment (*N*=13), Nontreatment (*N*=15), Treatment SEN (*N*=6), Nontreatment SEN (*N*=6).

	Treatment	Nontreatment	Treatment SEN	Nontreatment SEN
Mean	0.57	0.56	0.83	0.41
Median	0.59	0.60	0.82	0.40
p-value	0.01		5.34E-26	8.05E-35
Null	Reject		Reject	Reject

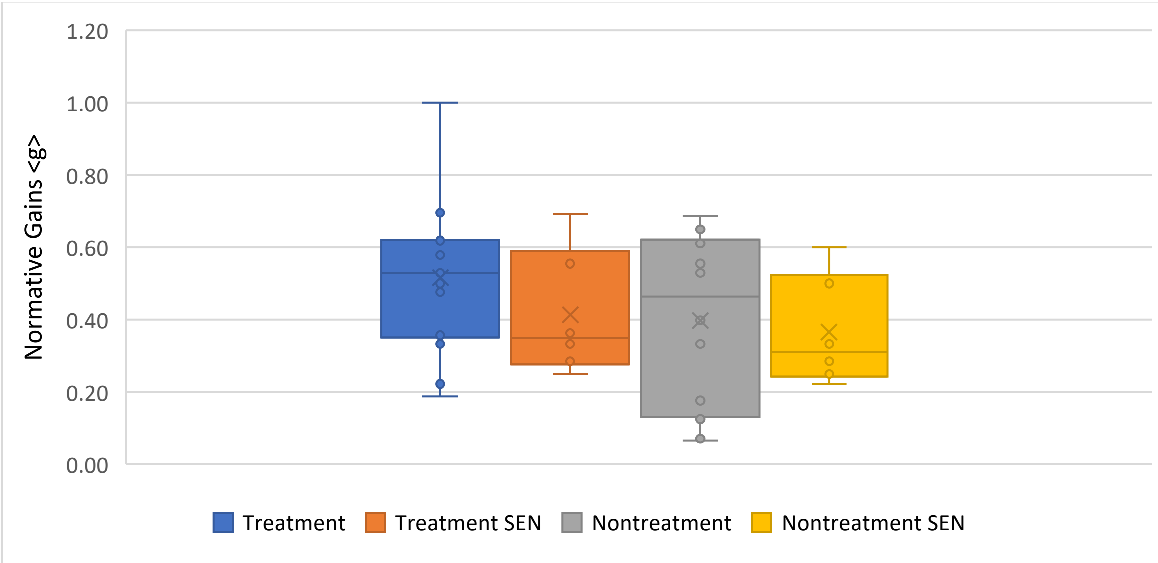

Figure 29. Box and whiskers diagram shows normative gains on their revision of the multiple-choice portion of Treatment 1: Cell Structure and Function. Normative gains of treatment and nontreatment groups are shown, and the SEN students in each group. Treatment (*N*=13), Nontreatment (*N*=15), Treatment SEN (*N*=6), Nontreatment SEN (*N*=6).

In the second treatment, students completed exam revisions on the multiple-choice portion of the unit exam following the posttest. Exam revisions allowed students to use any modality to explain how their understanding changed after reviewing. In Treatment 2, the treatment group, Grade 8 (G8), did not participate in exam revisions so a *p*-value comparing treatment and nontreatment groups could not be calculated. A comparison of normalized gains (<g>) between the nontreatment group and the SEN students in the same yielded a p-value less than 0.001. This meant that these students were supported by accommodations and modifications. Without revision data from the treatment group, no conclusions beyond this can be made (Table 21) (Figure 30).

Table 21. Mean and median normative gains on students' revision of the multiple-choice portion of Treatment 2: Organization of the Body Unit. Note that the treatment group did not participate in revision so a *p*-value could not be calculated. In the nontreatment group, students with special educational needs (SEN) are compared to their class. Treatment (*N*=0), Nontreatment (*N*=13), Treatment SEN (*N*=0), Nontreatment SEN (*N*=6).

	Treatment	Nontreatment	Treatment SEN	Nontreatment SEN
Mean	N/A	0.67	N/A	0.78
Median	N/A	0.78	N/A	0.76
p-value	N/A		N/A	2.08E-26
Null	N/A		N/A	Reject Null

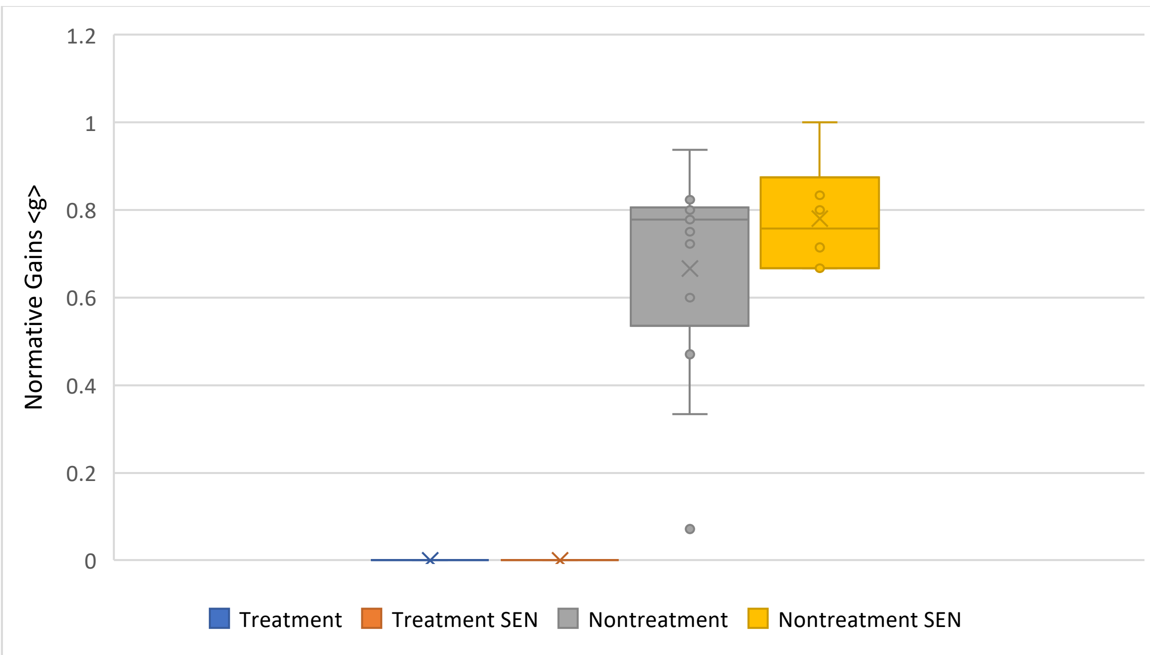

Figure 30. Box and whiskers diagram shows normative gains on their revision of the multiple-choice portion of Treatment 2: Organization of the Body. The treatment group did not participate in revisions. The nontreatment group participated and the normative gains for students with SEN are compared to the class. Treatment (*N*=0), Nontreatment (*N*=13), Treatment SEN (*N*=0), Nontreatment SEN (*N*=6).

The short answer portion of Treatment 1: Cell Structure and Function Unit Exam measured students' ability to apply content in new ways. Students' pretest and posttest scores were converted to normative gains (<g>) (Hake, 1998). The mean and median provide perspective on the data, but overall, with a *p*-value of 0.13, the results failed to provide evidence for this claim with statistical significance at the 5% significance level. When the treatment group SEN students' normative gains were compared to the treatment group overall, the *p*-value was less than 0.001. When the nontreatment SEN students' normative gains were compared to the nontreatment group overall, the *p*-value was less than 0.001. These *p*-values indicate significant difference between SEN students' normative gains compared to their classes' overall normative gains. Treatment 1 short answer posttest scores do not support the claim that UDL promotes students' ability to apply information in new ways. SEN students' multiple-choice revision scores in both treatment and nontreatment group indicate that accommodations and modifications support their learning needs, but not necessarily that this treatment did (Table 22) (Figure 31).

Table 22. Mean and median normative gains for the posttest on the short answer portion of Treatment 1: Cell Structure and Function Unit. *p*-values compare treatment to the nontreatment groups, but students with special educational needs (SEN) are compared to their class. Treatment (*N*=13), Nontreatment (*N*=15), Treatment SEN (*N*=6), Nontreatment SEN (*N*=6).

	Treatment	Nontreatment	Treatment SEN	Nontreatment SEN
Mean	0.27	0.19	0.20	0.09
Median	0.31	0.17	0.13	0.04
p-value	0.13		6.57E-29	6.94E-37
Null	Failed to Reject		Reject	Reject

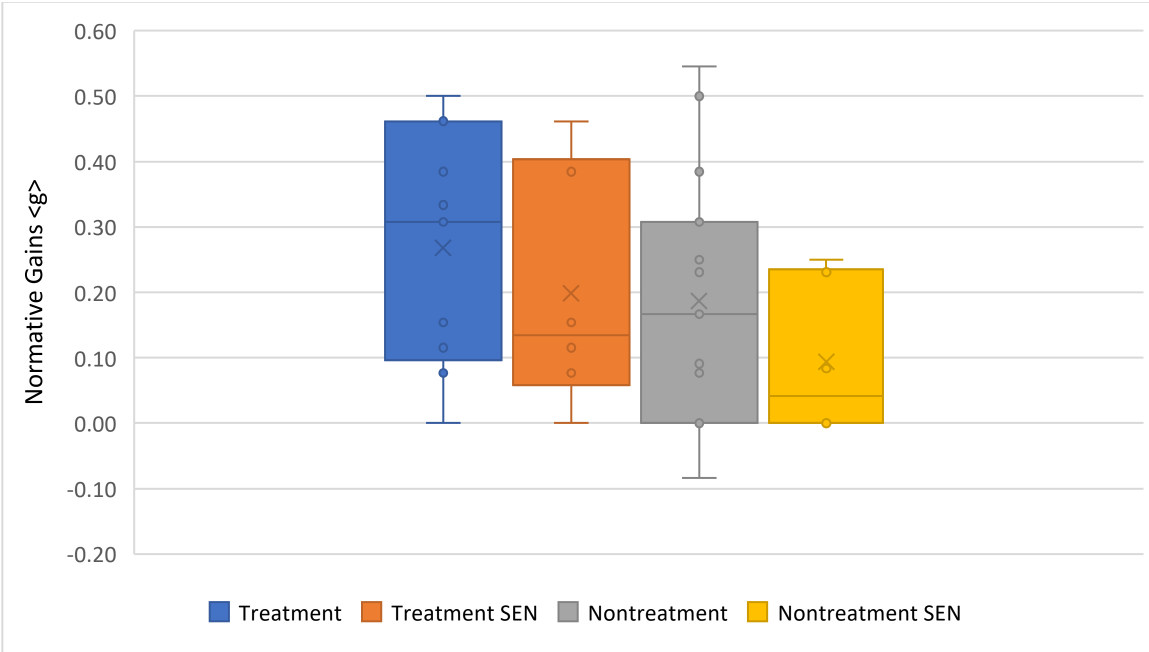

Figure 31. Box and whiskers diagram shows normative gains on their revision of the multiple-choice portion of Treatment 1: Cell Structure and Function. Normative gains of treatment and nontreatment groups are shown, and the SEN students in each group. Treatment (*N*=13), Nontreatment (*N*=15), Treatment SEN (*N*=6), Nontreatment SEN (*N*=6).

In Treatment 1, both treatment and nontreatment groups revised their short answer responses using new evidence. Students' pretest and revision scores were converted to normative gains (<g>) (Hake, 1998). The mean and median provide perspective on the data, but overall, with a *p*-value of 0.20, the results failed to provide evidence for this claim with statistical significance at the 5% significance level. When the treatment group SEN students' normative gains were compared to the treatment group overall, the *p*-value was less than 0.001. When the nontreatment SEN students' normative gains were compared to the nontreatment group overall, the *p*-value was less than 0.001. These *p*-values indicate significant difference between SEN students' normative gains for revision compared to their classes' overall normative gains. Treatment 1 short answer revision scores do not support the claim that UDL promotes students' ability to apply information in new ways. SEN students' short answer revision scores in both treatment and nontreatment group indicate that accommodations and modifications support their learning needs, but not necessarily that this treatment did (Table 23) (Figure 32).

Table 23. Mean and median normative gains on students' revision of the short answer portion of Treatment 1: Cell Structure and Function Unit. *p*-values compare treatment to the nontreatment groups, but students with special educational needs (SEN) are compared to their class. Treatment (*N*=13), Nontreatment (*N*=15), Treatment SEN (*N*=6), Nontreatment SEN (*N*=6).

	Treatment	Nontreatment	Treatment SEN	Nontreatment SEN
Mean	0.36	0.27	0.36	0.18
Median	0.46	0.25	0.34	0.06
p-value	0.20		2.19E-28	2.32E-36
Null	Failed to Reject		Reject	Reject

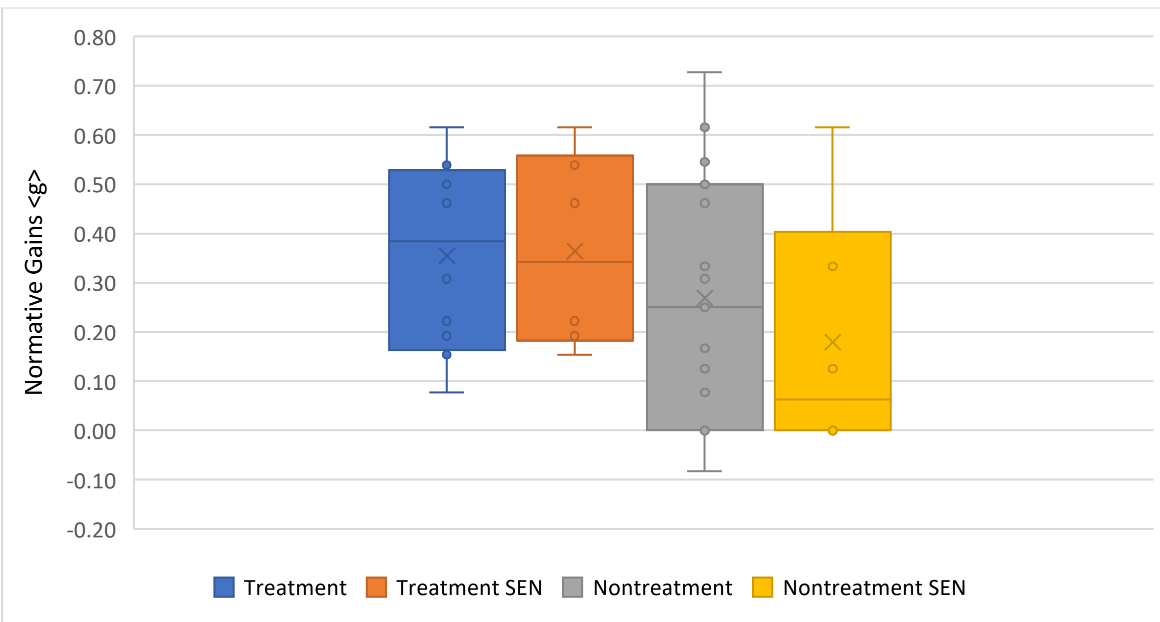

Figure 32. Box and whiskers diagram shows normative gains on their revision of the short answer portion of Treatment 1: Cell Structure and Function. Normative gains of treatment and nontreatment groups are shown, and the SEN students in each group. Treatment (*N*=13), Nontreatment (*N*=15), Treatment SEN (*N*=6), Nontreatment SEN (*N*=6).

In the second treatment, the short answer portion of the Organization of the Body Unit Exam measured students' ability to apply content in new ways. Students' pretest and posttest scores were converted to normative gains (<g>) (Hake, 1998). The mean and median provide perspective on the data, but overall, with a *p*-value of 0.31, the results failed to provide evidence for this claim with statistical significance at the 5% significance level. When the treatment group SEN students' normative gains were compared to the treatment group overall, the *p*-value was less than 0.001. When the nontreatment SEN students' normative gains were compared to the nontreatment group overall, the *p*-value was less than 0.001. These *p*-values indicate significant difference between SEN students' normative gains for revision compared to their classes' overall normative gains. Treatment 2 short answer posttest scores do not support the claim that UDL promotes students' ability to apply information in new ways. SEN students' short answer posttest scores in both treatment and nontreatment group indicate that accommodations and modifications support their learning needs, but not necessarily that this treatment did (Table 24) (Figure 33).

Table 24. Mean and median normative gains on the short answer portion of Treatment 2: Organization of the Body Unit. *p*-values compare treatment to the nontreatment groups, but students with special educational needs (SEN) are compared to their class. Treatment (*N*=13), Nontreatment (*N*=15), Treatment SEN (*N*=6), Nontreatment SEN (*N*=6).

	Treatment	Nontreatment	Treatment SEN	Nontreatment SEN
Mean	0.64	0.52	0.66	0.46
Median	0.70	0.67	0.73	0.53
p-value	0.31		3.28E-34	1.55E-27
Null	Failed to Reject		Reject Null	Reject Null

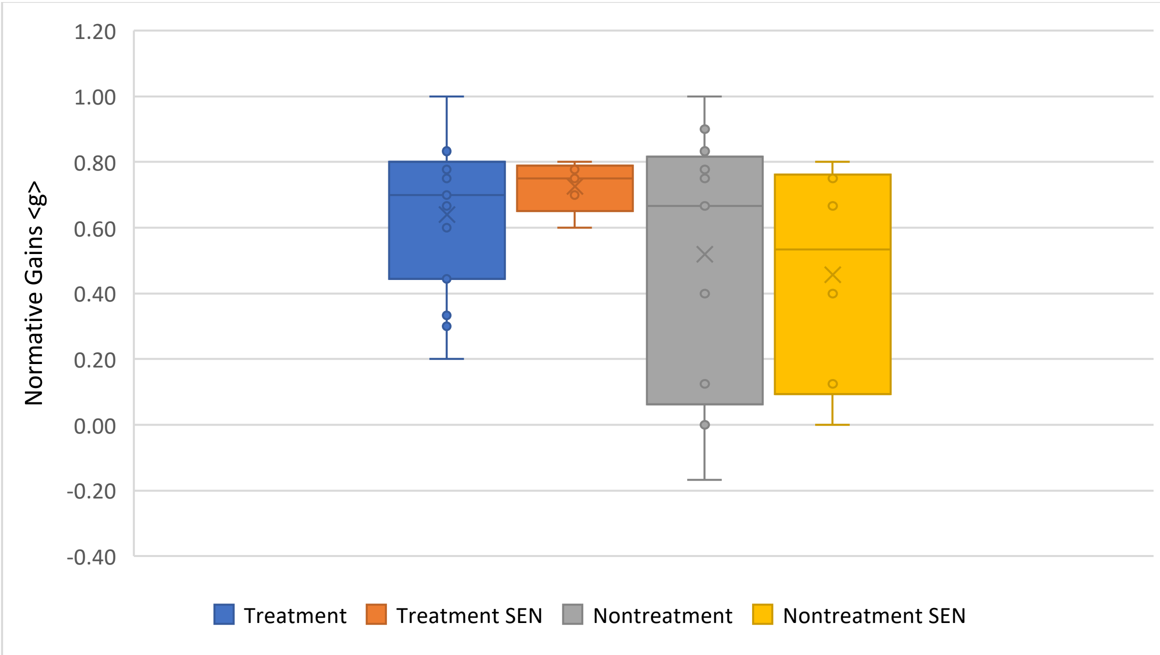

Figure 33. Box and whiskers diagram shows normative gains on their revision of the short answer portion of Treatment 2: Organization of the Body. Normative gains of treatment and nontreatment groups are shown, and the SEN students in each group. Treatment (*N*=13), Nontreatment (*N*=15), Treatment SEN (*N*=6), Nontreatment SEN (*N*=6).

In the second treatment, students revised their short answer responses using new evidence. Students' pretest and revision scores were converted to normative gains (<g>) (Hake, 1998). The treatment group did not participate in exam revisions so a *p*-value comparing treatment and nontreatment groups could not be calculated. A comparison of normalized gains (<g>) between the nontreatment group and the SEN students in the same yielded a *p*-value less than 0.001. Treatment 2 short answer posttest scores do not support the claim that UDL promotes students' ability to apply information in new ways. SEN students' short answer posttest scores in both treatment and nontreatment group indicate that accommodations and modifications support their learning needs, but not necessarily that this treatment did (Table 25) (Figure 34).

Table 25. Mean and median normative gains on students' revision of the short answer portion of Treatment 2: Organization of the Body Unit. Note that the treatment group did not participate in revision so a *p*-value could not be calculated. In the nontreatment group, students with special educational needs (SEN) are compared to their class. Treatment (*N*=0), Nontreatment (*N*=13), Treatment SEN (*N*=0), Nontreatment SEN (*N*=6).

	Treatment	Nontreatment	Treatment SEN	Nontreatment SEN
Mean	N/A	0.61	N/A	0.62
Median	N/A	0.78	N/A	0.63
p-value	N/A		N/A	4.73E-27
Null	N/A		N/A	Reject Null

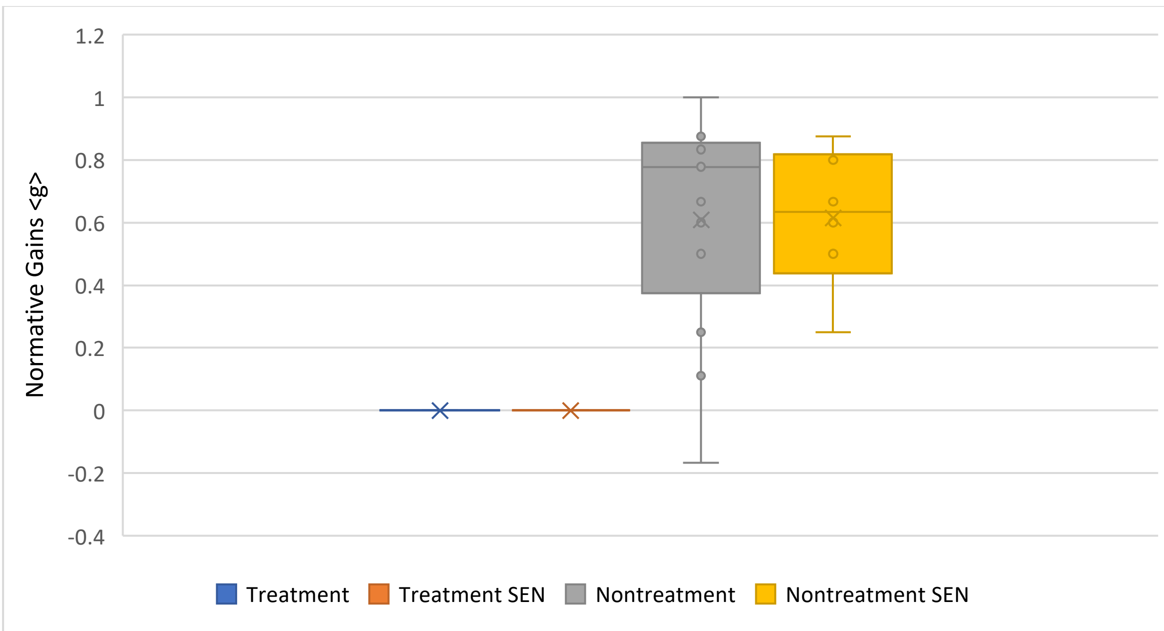

Figure 34. Box and whiskers diagram shows normative gains on their revision of the multiple-choice portion of Treatment 2: Organization of the Body. The treatment group did not participate in revisions. The nontreatment group participated and the normative gains for students with SEN are compared to the class. Treatment (*N*=0), Nontreatment (*N*=13), Treatment SEN (*N*=0), Nontreatment SEN (*N*=6).

Treatment groups completed three Application Cards over the course of a unit. Each Application Card had a three-point value. The mean is provided as well as the percent participation by treatment group. The first treatment was Grade 7 (G7) and the second treatment was Grade 8 (G8) (Table 26) (Table 27) (Figure 35) (Figure 26).

Table 26. Mean scores on the three-point Application Cards for Treatment 1: Cell Structure and Function. Percent participation is shown by treatment group and sub-group. Treatment 1 (N=13), Treatment 1 SEN (N=6).

	Treatment 1	Treatment 1 SEN	Class Participation	SEN Participation
AC1	2.6	2.6	77%	83%
AC2	3.0	3.0	85%	83%
AC3	2.9	3.0	85%	67%

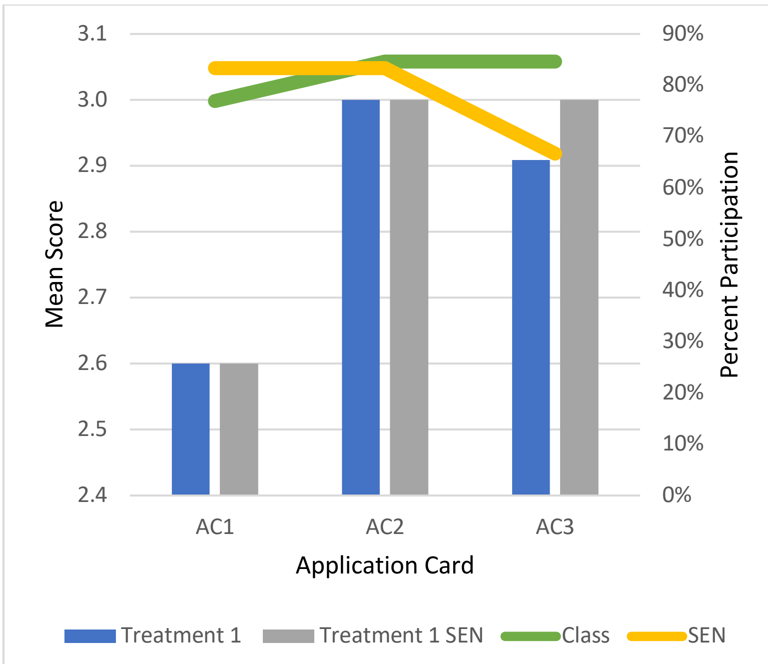

Figure 35. Mean scores shown by Application Card for Treatment 1: Cell Structure and Function for the class and for students with SEN. On the secondary axis, percent participation is shown by class and the sub-group of students with SEN. Treatment 1 (N=13), Treatment 1 SEN (N=6).

Table 27. Mean scores on the three-point Application Cards for Treatment 2: Organization of the Body. Percent participation is shown by treatment group and sub-group. Treatment 2 (N=15), Treatment 2 SEN (N=6).

	Treatment 2	Treatment 2 SEN	Class Participation	SEN Participation
AC1	2.6	2.8	67%	83%
AC2	2.1	1.8	73%	83%
AC3	2.7	2.3	47%	50%

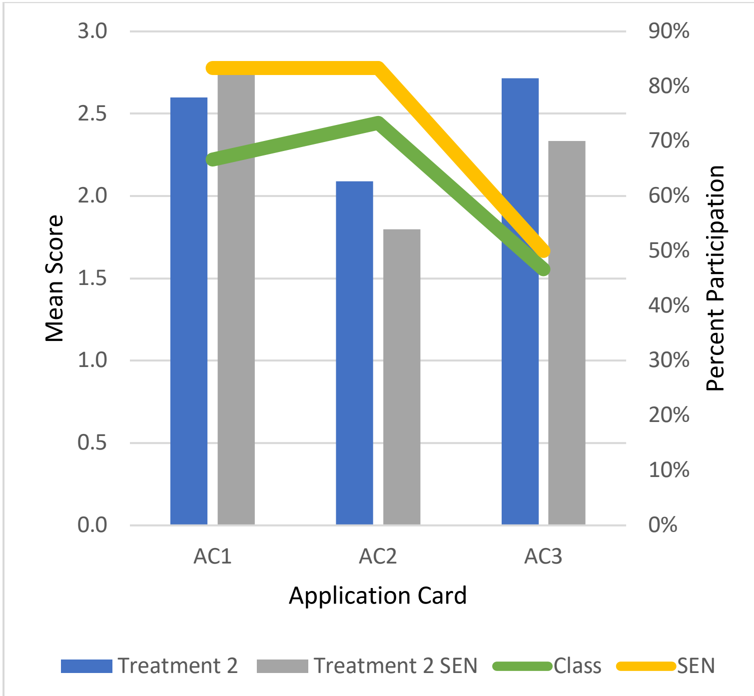

Figure 36. Mean scores shown by Application Card for Treatment 2: Organization of the Body for the class and for students with SEN. On the secondary axis, percent participation is shown by class and the sub-group of students with SEN. Treatment 2 (N=15), Treatment 2 SEN (N=6).

Science and Engineering Fair projects provided students with the opportunity to apply ideas in new ways. A series of selected posters from Grade 7 and Grade 8, both science and engineering projects, are shown below (Figure 37) (Figure 38) (Figure 39) (Figure 40) (Figure 41) (Figure 42) (Figure 43) (Figure 44) (Figure 45) (Figure 46) (Figure 47). Outside judges, themselves experts in fields of science and engineering, were invited to interview and assess students' projects. The winners from Grades 7 and 8 are also included as sample.

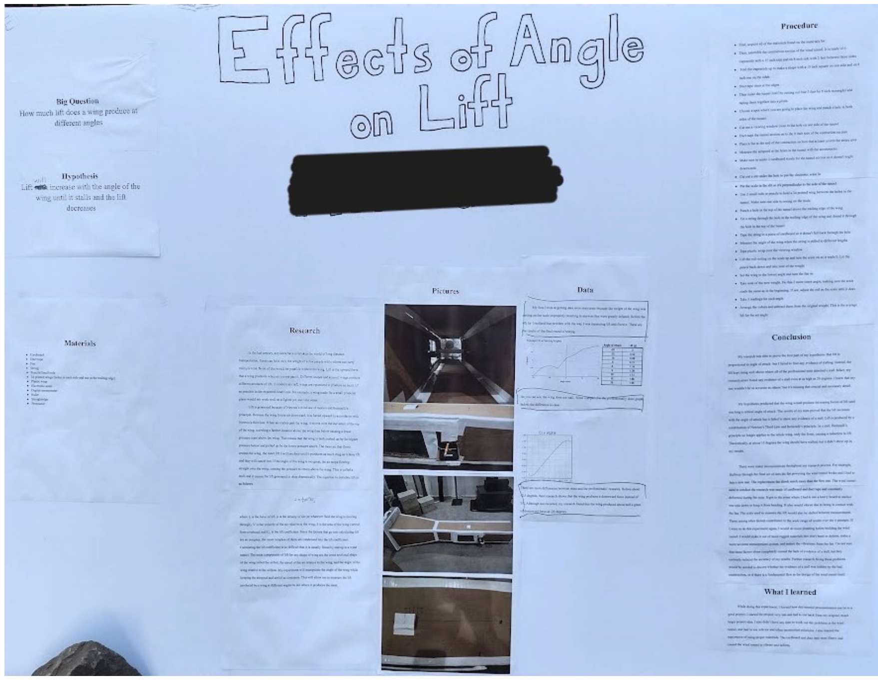

Figure 37. This G8 engineering project won Best Engineering Overall. This student does not have accommodations or modifications.

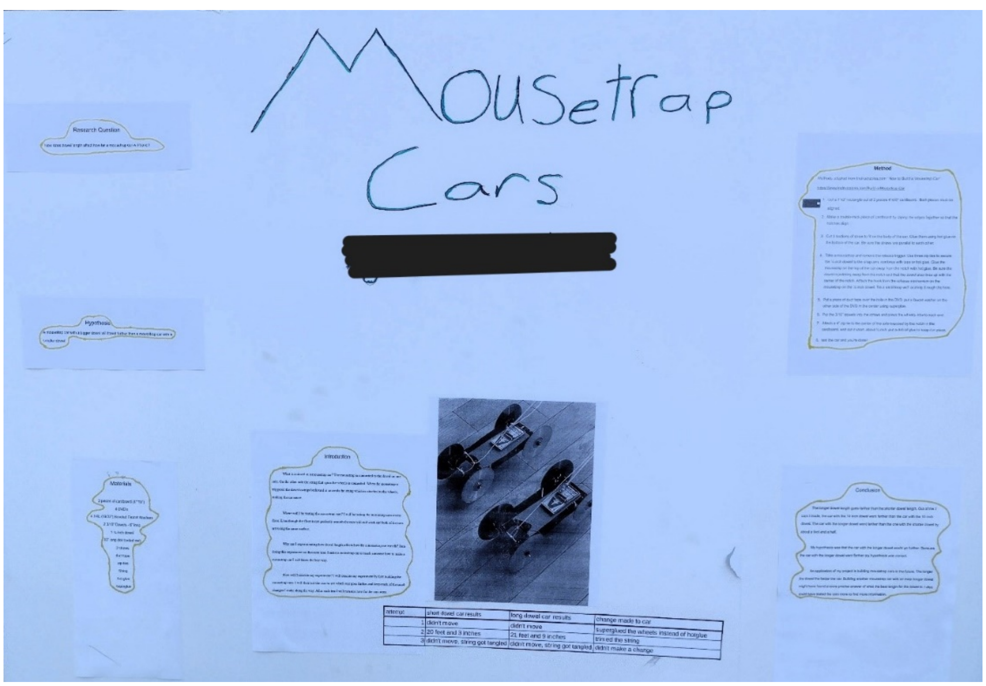

Figure 38. This G8 engineering project won G8 Best Engineering Project. This student has an IEP for specific learning disorders.

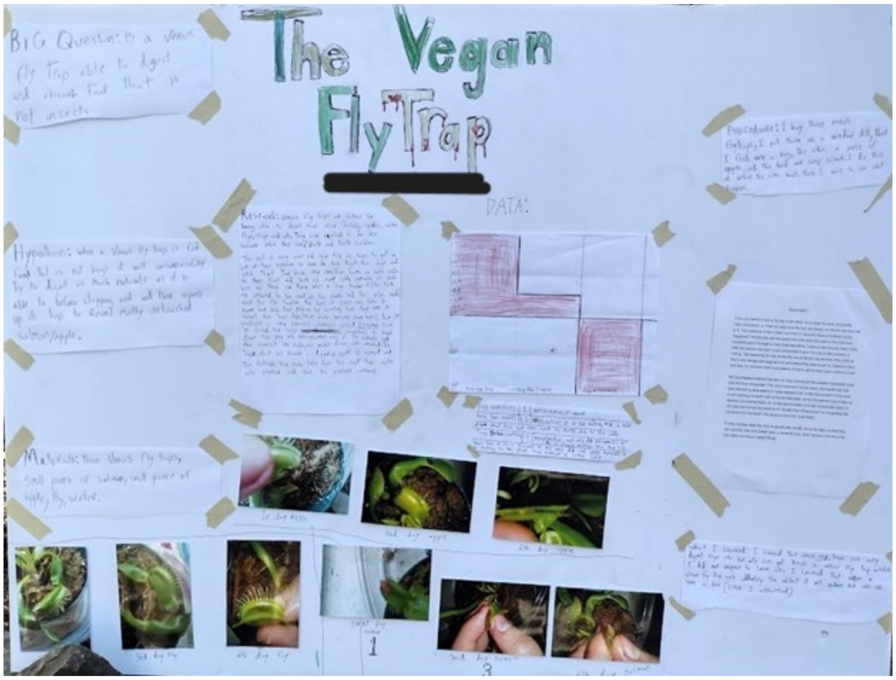

Figure 39. This G8 science project won G8 Best Science Project. This student has varied, in-house accommodations and modifications for learning differences and behavior.

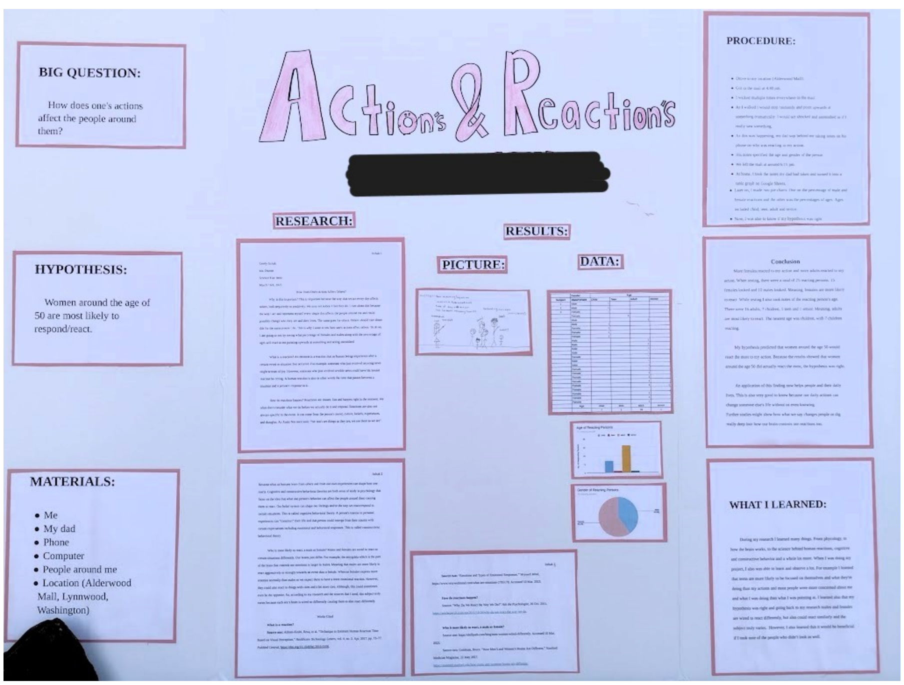

Figure 40. This G8 science project was discussed as a runner up for Best G8 Science Project. This student has varied, in-house accommodations and modifications for learning differences.

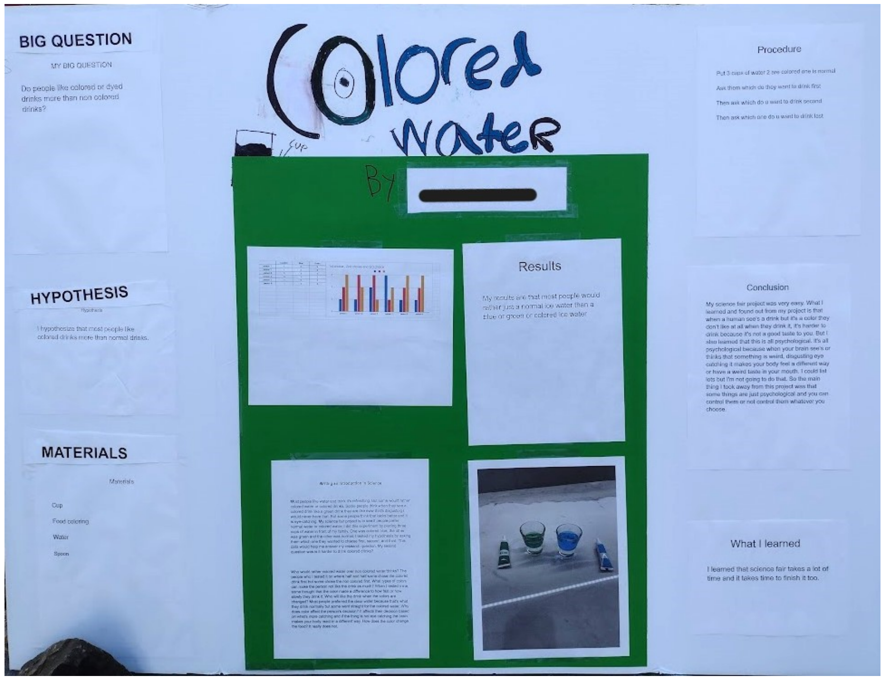

Figure 41. This G8 science project was completed by a student with varied, in-house accommodations and modifications for learning differences and behavior.

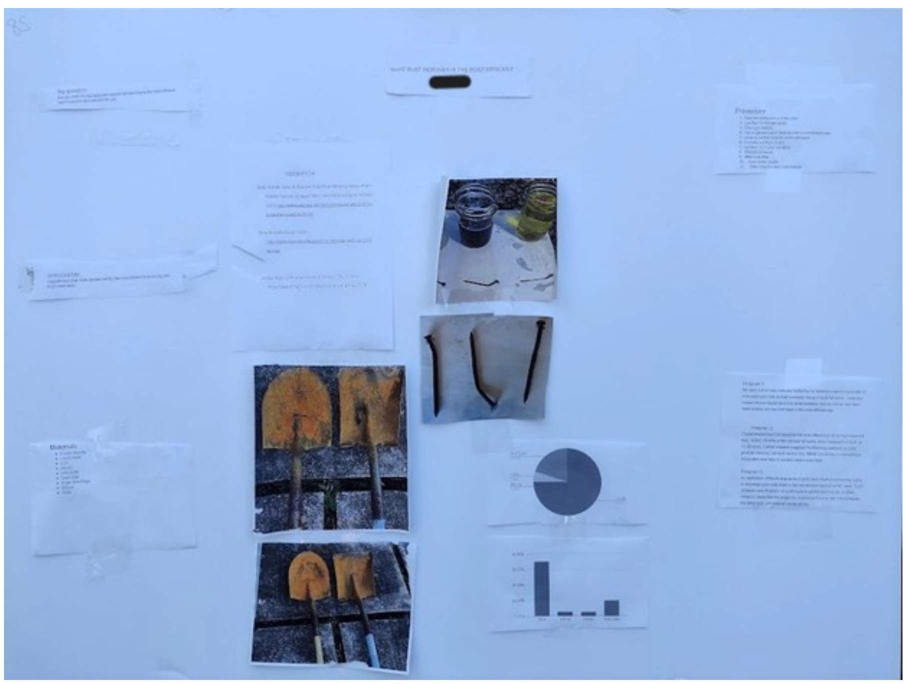

Figure 42. This G8 science project was completed by a student with no accommodations or modifications.

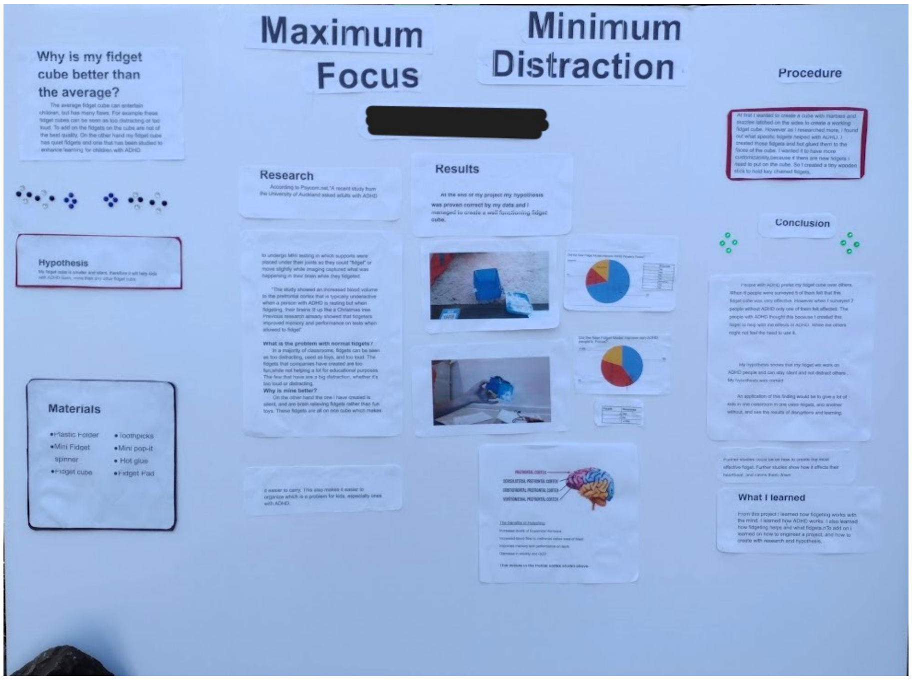

Figure 43. This G7 engineering project won G7 Best Engineering Project. This was a passion project for a student who has varied, in-house accommodations for ADHD.

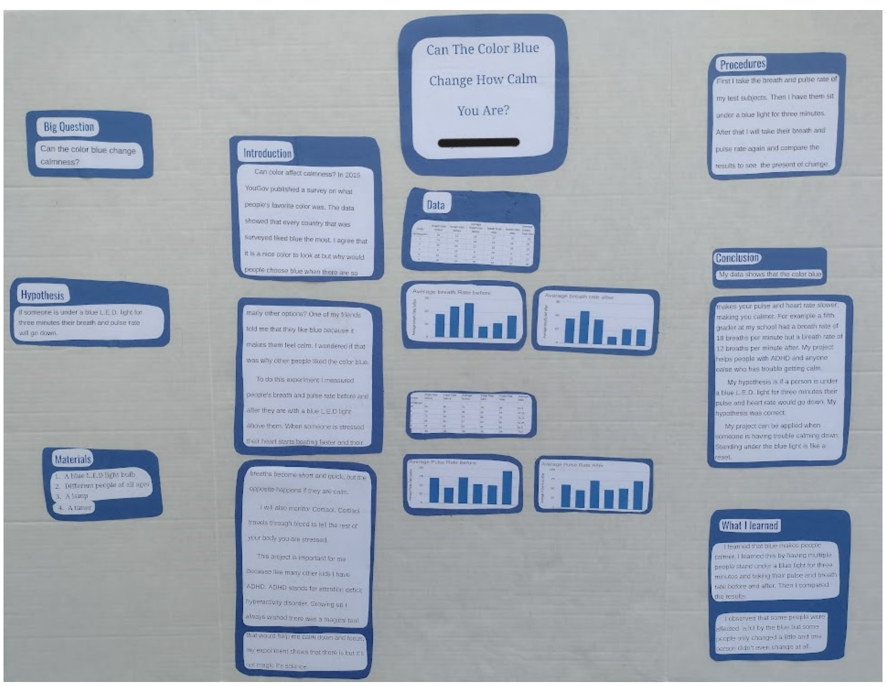

Figure 44. This G7 science project won G7 Best Science Project. This student has varied, in-house accommodations and modification for learning differences and behavior.

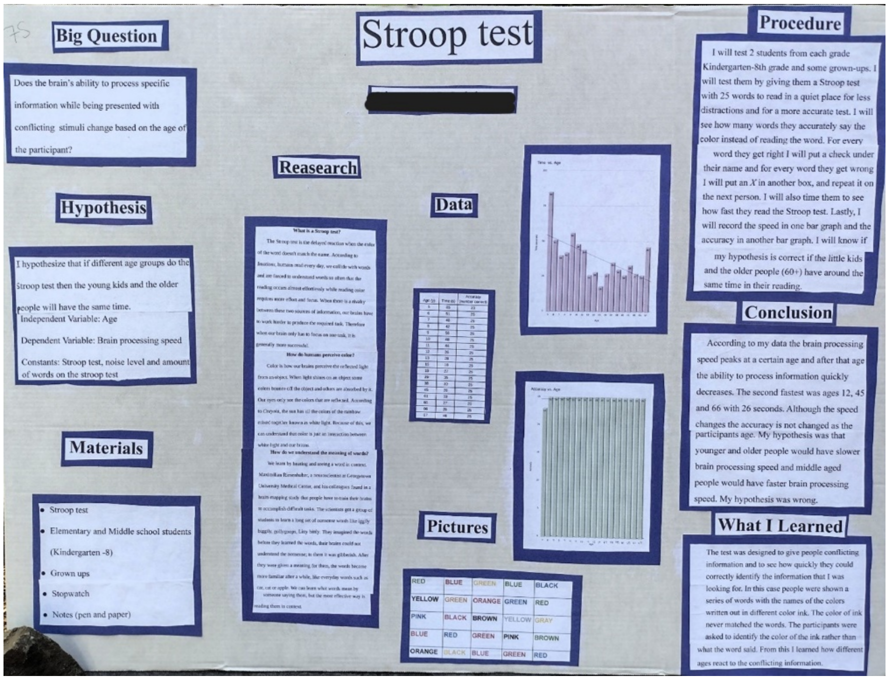

Figure 45. This G7 science project was discussed by the judges as a runner up for G7 Best Science Project. This student does not have accommodations or modifications.

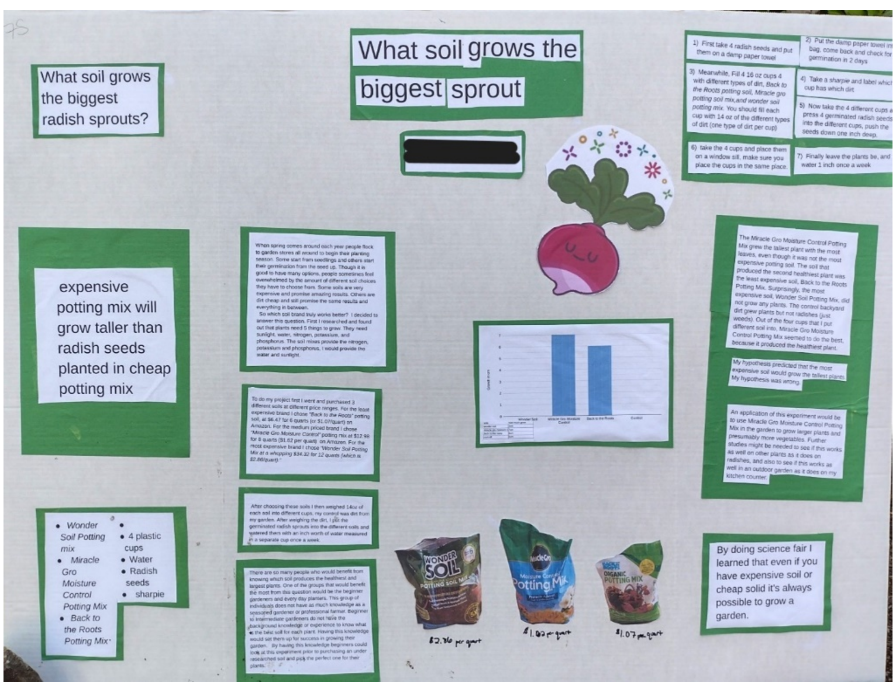

Figure 46. This G7 science project was completed by a student with an IEP for specific learning disorders and varied, in-house modification and accommodations for behavior.

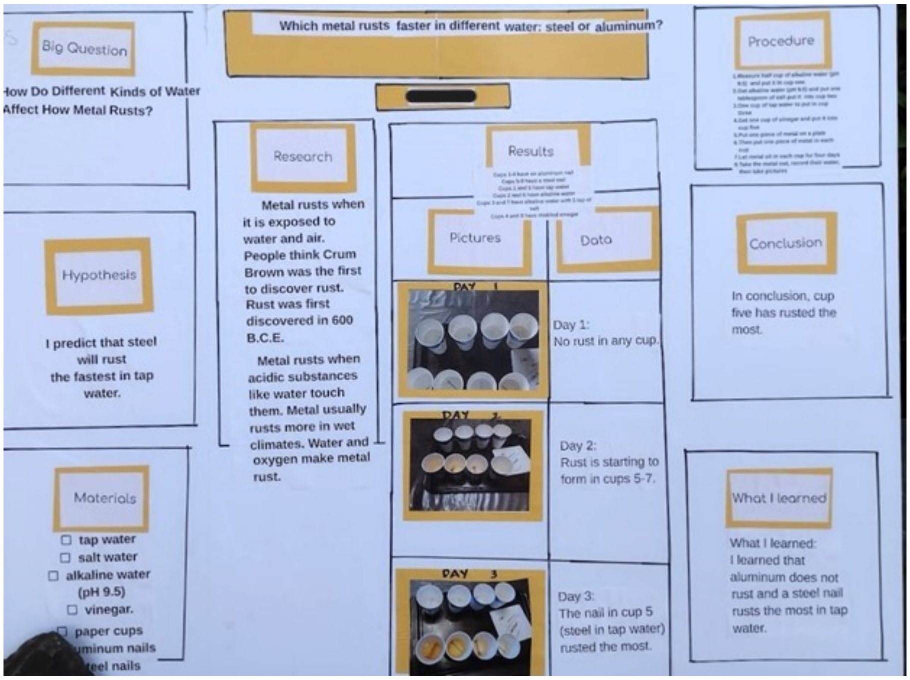

Figure 47. This G7 science project was completed by a student with varied, in-house accommodations and modifications for learning differences and behavior.

CLAIMS, EVIDENCE, AND REASONING

The results are inconclusive if Universal Design for Learning (UDL) promotes students' learning of new content. UDL's principles revolve around representation of content to the learners, action and expression of the learners' growth, and engagement of learners in the community of the classroom. All three are relevant in creating a classroom that progresses and promotes excellence in all learners. This claim derives its evidence from students' normative gains for the pretest and posttest unit exams and by students' mean scores on key concepts from the Science and Engineering Fair projects. These key concepts are found on the project rubrics used to assess the projects.

The unit exam was the instrument measuring students' experience of the content and addressed the UDL principle of representation. The *p*-value correlating the normative gains between the pretest and posttest indicated whether the content delivery was effective. For the first treatment, in the Cell Structure and Function Unit, the *p*-value of 0.20 was not significant to support the claim. The treatment group's mean normative gain was 0.35 and the nontreatment group's mean normative gain was 0.23. The mean normative gain for students with special educational needs (SEN) in both treatment and nontreatment groups were 0.56 and 0.29, respectively. For both SEN groups, their normative gains were compared to their respective classes and in both cases, the *p*-value was significantly less than 0.001. Because SEN students, by law, are required to receive accommodations and modifications, these results simply suggest that accommodations and modifications support SEN students but not necessarily that this treatment did. A similar effect was observed in the second treatment, Organization of the Body Unit. Here, the *p*-value of 0.40 meant gains were outside of the 5% significance level and the claim unsupported. The treatment group's mean normative gain was 0.52 and the nontreatment group's 0.40. As in the first treatment, the mean normative gain for SEN students in both treatment and nontreatment groups were 0.41 and 0.37, respectively. For both SEN groups, their normative gains were compared to their respective classes and in both cases, the *p*-value was significantly less than 0.001, supporting the claim. But once again, this suggests that accommodations and modifications support SEN students but not necessarily that this treatment did. Overall, the first and second treatments do not support the claim that UDL promotes students' learning of new content.

The third treatment, Science and Engineering Fair, did not have a comparative component but students' mean scores on key concepts served as supporting evidence. Scores were awarded by the standards outlined on the Science Project Rubric and the Engineering Project Rubric. The key concepts for science projects were creating an idea, developing a hypothesis, identifying the variables and control, and listing several relevant constants. The key concepts for engineering were identifying a problem, developing a prototype, outlining important parameters, comparing alternatives, and defending the final prototype. A successful mean score was above a 3.5, a value established at Seattle Hebrew Academy (SHA) correlating with 85-89%. For students in Grade 7 and Grade 8 who completed a science project, mean scores were at or above the 3.5 threshold for three of the five key concepts. SEN students from both grades were above the 3.5 threshold for three of the five key concepts. All Grade 7 students would have benefitted from increased support with identifying variables and constants, while Grade 8 SEN students needed increased support identifying variables and a control. For engineering projects, both grades exhibited means above the 3.5 threshold for four of the five key concepts, while SEN students in each performed at or above it for all key concepts. The third treatment suggests that UDL does support students' ability to learn content.

Students' engagement with the content influenced their learning of it. Older UDL materials list engagement after the principles of representation and action and expression, but more recent materials place engagement ahead of them (CAST, 2023). Through individual and group interviews, students shared their perception of their learning experience. In the first treatment, Cell Structure and Function, neither the treatment nor nontreatment group expressed a great connection to the content. In the second treatment, Organization of the Body, only 27% of the students in the treatment group found the content memorable, considerably less than the 69% of the nontreatment group. In group interviews, 92% of the first treatment did not care for the UDL-aligned content packets I created. The nontreatment group simply had packets photocopied from the text and 87% of these students did not care for them. In the second treatment, 100% of the treatment group listed that they appreciated the lack of content packets. It was not true that there were no packets, but their perception of them not existing leads me to conclude that these were effective tools. Confusingly, in the second treatment, 100% of the nontreatment group appreciated the textbook photocopied packets. Students' conflicting perceptions of the content and the UDL reading packets do not support the claim that UDL promotes students' learning of new content.

Because it is standard practice, both treatment and nontreatment groups received study guides. Study guides naturally follow UDL principles, incorporating even more UDL checkpoints when students are provided ample time to collaborate on summarizing their learning. In the first treatment, 62% of the treatment group did not care for the study guide format and 87% of the nontreatment group agreed with them. They both received the same study guide. In the second treatment, 100% of the treatment group did not care for the study guide format and 54% of the nontreatment felt the same. They both received the same study guide. Midway through the second treatment, I learned why: students explained to me that, at Seattle Hebrew Academy, study guides are given with the question and the answer. My study guides were the first time they had to review content, summarize it, and then derive meaning from it. With regards to the study guides, students' negative perception of them does not support the claim that UDL promotes students' learning of new content.

The Human Tableau served as one of the instruments of UDL content representation. In the individual interviews, 31% of the students in Treatment 1 and 20% of the students in Treatment 2 found it to be memorable. Later, in group interviews with the first treatment group, 38% of the students found the Human Tableau to have been an overall positive learning experience, while in the second treatment, it was not even mentioned. Part of the reason for its omission from Treatment 2 could be because the performance of the activity was cancelled due to unsafe behavior. The outcome of the activity was never experienced. This information does suggest there are other factors influencing the classroom. Overall, these results do not lend support to the claim that UDL promotes student learning of new content.

In the first treatment, 69% of the treatment group indicated that the content delivery seemed chaotic and very busy. This could be the result of two factors: the first factor was the Science and Engineering Fair occurring in the middle of the unit, and the second factor was a colleague's unexpected chocolate factory tour also in the middle of the unit. Teachers were asked to plan something around chocolate and in response, I created a Chemistry of Chocolate activity around UDL principles. It was presented to both groups. Seventy-seven percent of the treatment group did not like this unexpected UDL activity, but the nontreatment group did not mention it at all. This information suggests there are other factors influencing the classroom. Overall, students' negative experience with the content delivery and general busyness do not lend support to the claim that UDL promotes students' learning of new content.

Engagement through the Treatments 1 and 2 was also measured through student interest surveys, with questions focused on their attitudes towards inquiry, development of scientific thinking, and enjoyment of science class. Differences between pretreatment and posttreatment surveys produced *p*-values with no significant changes between the two. To derive a general feeling for students' changing attitudes, I found the difference between each students' surveys and found the mean of these differences. Again, while nothing was significant, in Treatment 1, trends in the treatment group suggested these students would rather learn by experimentation and that they are flexible in their thinking, Trends for students in the nontreatment group suggested that they are comfortable reporting both expected and unexpected results from an experiment. Trends for Treatment 2 indicated that the treatment group was curious about the world but also that science class was a waste of time. Interestingly, in the second treatment, the trend of the means for Grade 8 SEN students and all Grade 7 students suggest they enjoy science class. Overall, given that results from surveys were insignificant, these evidences cannot be used to support or nullify the claim that UDL promotes students' learning of new content.

Students' engagement through the third treatment, Science and Engineering Fair (S&E Fair), shed light on the observed means for the key concepts. Forty percent of students from both Grades 7 and 8 felt that there was less time than the previous year. Combined, 25% felt that S&E

Fair helped them build their content knowledge. Though the group interview only had seven students, all listed content retention as an academic skill they built through their project. Also in the group interview, 100% of participants said communication was better this year, even though 86% said it was more stressful. Engagement through the third treatment supports the claim that UDL promotes students' learning of content, especially with respect to science and engineering practices.

Claim 2: UDL promotes students' ability to apply content in new ways.

This claim derives its support from students' normative gains for revision on unit exams; from the normative gains made for the posttest and revisions of the short answer portion on unit exams; from their mean scores and percent participation on Application Cards; and by their participation in Science and Engineering Fair. Exam revisions follow UDL checkpoints related to students' ability to assess what they know and apply it. In Treatments 1 and 2, normative gains compared the revision scores to pretest scores. In the first treatment, students revised their multiple-choice portion, with the mean normative gain for the treatment group was 0.57 and the nontreatment group was 0.56. When compared to their pretests, the p-value of 0.01 indicates that gains were statistically significant and supports the claim. Unfortunately, in Treatment 2, the treatment group opted not to participate in exam revisions and therefore, a comparison for statistical relevance could not be made. Again, SEN students in both treatments experienced significant learning gains with p-values less than 0.001 when compared to their respective classes. This provides evidence that accommodations and modifications support SEN students' ability to apply information in new ways, but not necessarily that this treatment did. Considering only the first treatment, UDL appears to support students' ability to apply content in new ways.

While this could also be used as support for this project's first claim – that UDL supports students' learning of content – it was not the original intention of this activity.

The short answer portion of unit exams asked questions reminiscent of PISA-style questions. In Treatment 1, the mean posttest normative gain for the treatment group was 0.27 and the mean posttest normative gain for the nontreatment group was 0.19. The analysis resulted in a *p*-value of 0.13, outside of the 5% significance level. In Treatment 2, the mean posttest normative gain for the treatment group was 0.64 and the mean posttest normative gain for the nontreatment group was 0.52. The analysis resulted in a *p*-value of 0.31, outside of the 5% significance level. In both treatments and in both grades, SEN students' normative gains compared to their classmates' normative gains resulted in *p*-values less than 0.001, indicating that, on the short answer posttest, they made statistically significant gains when compared to their peers. The short answer revision scores, compared to the pretest, likewise did not produce statistically significant gains in Treatment 1. With a *p*-value of 0.20, there was not enough evidence to support the claim. In Treatment 2, the treatment group opted not to participate in revision. As with their short answer posttest scores, SEN students who participated in the revisions experienced significant gains compared to their peers, again indicating that accommodations and modifications support their ability to apply content in new ways. Considering the results from the short answer instruments, UDL does not promote students' ability to apply information in new ways.

In each unit, treatment groups completed three Application Cards, valued at three points each. In the first treatment, mean scores on these instruments ranged from 2.6-3.0, reflecting that those who completed the cards creatively applied content in new ways. Percent participation in the first treatment ranged from 77-85% for the class and with the sub-group of SEN students participating between 67-83%. In the second treatment, means scores on these instruments ranged from 1.8-2.8 with participation ranging from 47-73% overall and SEN students' participation ranging from 50-83%. Treatment 1 students engaged more with the application process than the Treatment 2 students, resulting in better outcomes overall. This UDL activity weakly supports the claim that UDL promotes students' ability to apply information in new ways.

Science and Engineering Fair projects are the ultimate of UDL activities and students enthusiastically participated in the ideation, practice, and presentation of their projects. Posters evidenced in Chapter 4 show that general education students and students with special educational needs both found success in this project, each working to the best of their interest and ability. In this activity, I invited science and engineering experts from around the Seattle area to judge our students' projects. Judges included a retired Boeing engineer, a nuclear physicist, an environmental health scientist and professor, and two cognitive science PhD candidates from the University of Washington. They interviewed all the students, reviewed their posters, focused on the practices of science and engineering, and determined how well the students understood their projects. Following deliberation without interference from me, judges awarded prizes to the students. There were nine prizes available, with five available to Grade 7 and five to Grade 8. These prizes were: Best Engineering Project Overall, Best Science Project Overall, a grade level Best Engineering Project, a grade level Best Science Project, and a Judges' Choice Award. The Judges' Choice was reserved for a particular favorite that might not be strong in the science or engineering practices. It is important to note that the Best Engineering and Science Projects for both grades all went to SEN students. The third treatment supports the claim that UDL promotes students' ability to apply information in new ways.

Value of This Study

UDL appears promising as a framework for meeting the learning needs for students with IEPs and Section 504 plans in the science classroom. In this project, learning gains and the ability to apply new ideas in novel scenarios were significant in students with accommodations and modifications. While the learning gains for all students were not significant, the employment of the UDL framework was not detrimental to them. As an architectural concept, this is a stated goal of universal design. North Carolina State University's College of Design, where the concept was born, elaborates on its first principle, equitable use: a design should be pleasing to use; should be used in the same manner by all but made equivalent when adjustments must be made; and should not stigmatize those using the design (NCSU College of Design, 2023). In the classroom, the relevant designs are those of teaching and learning.

My initial experiences with UDL were of two flavors: one was too general and philosophical to be useful, and the other was too specific to embody the scope of universal design. Teaching websites discussing UDL restated the principles, mentioned the importance of flexibility and choice but provided no concrete tools to achieve these aims. On the other hand, administrators would send out weekly newsletters with a recurring section dedicated to helpful UDL strategies. These excellent activities, like think-pair-share, jigsaws, and gallery walks, are used by many educators already. Viewing UDL solely as a collection of specific strategies conveys that UDL is merely a technique. It does not convey that it is a fundamental shift in how educators and learners interact in a full-UDL classroom. Sewell, et al. at University of Worcester described that the UDL effort represents an attitudinal change. This change means moving away from retrofitting the curriculum to meet students' needs by providing accommodations, modifications, and specialists. To me, UDL represents not only an attitudinal change but also a shift in the culture of education, away from the concept of a norm and differences from the norm and moves towards authentic inclusion. Achieving this requires more than a one-day workshop (Sewell, et al., 2022).

I see professional learning communities (PLCs) at the school level as key to improving access to science education for all. PLCs also can ease the shift towards a full-UDL classroom. UDL principles provide a framework for a classroom community: representation, action and expression, and engagement (CAST, 2023). These three pillars together build a cohesive, progressing, and positive learning environment. I focused this project on the methods of content delivery and the methods of assessment – the first two principles. But as surveys and interviews showed, the student engagement piece was lacking. Working in PLCs can provide support for addressing these factors while also developing deeper understandings of the guidelines and creating activities and assessments that reflect checkpoints. As a team, each educator can then develop a deeper understanding of how a classroom stripped of barriers operates.

My students in Treatment 1 indicated that they felt confused and that the learning felt chaotic at times. I believe this reflects abrupt shift to a full-UDL classroom for two treatment units and without much warning to the students. Many UDL techniques are used in the classroom already and students are familiar with them. A scaffolded introduction to instruments like surveys and interviews early in the school year might help to build a stronger engagement piece and open continual dialogue throughout the school year. Because the Science and Engineering

Fair proved successful for both claims, I would like to develop more long-term projects with embedded student choice for the engagement piece.

Impact of Action Research on the Author

The 18 months teaching my private student as he struggled through online learning exposed how insufficient my teaching methods were. It became unacceptable for me to continue in that manner. I identified a problem. While looking for resources to support him, I encountered UDL and superficially understood it to mean accommodations for all. I read websites about UDL. I interviewed adults with learning differences about their experiences. I interviewed educators who teach students with learning differences. I was gathering data. In interviews with adults who have learning differences, they shared with me what helped them, what hindered them, and what adjustments they make to their lives today. I used this information to influence the development of my project. The project expanded to include multiple instruments to gather data. It quickly became muddled.

Action research should be a simple question that is easily testable, very much like a hypothesis but a better corollary would be the engineering design process. In engineering design, a problem is identified, a prototype proposed with parameters defined. This prototype is tested, reviewed, and rebuilt. It is retested until a design fulfills its original intended purpose. Here again, the design is of instruction. This project encompassed too much to be a clean action research project, but it was the project I needed to do to change my pedagogy.

Flexibility and choice create a more fluid learning environment and should be fun to plan. In this project, I dove into full-UDL and at times, it was not fun. I designed two treatment units attempting a full-UDL framework with no experience beyond what I had read. My students reported that, at times, instruction felt confusing and the activities odd. As their teacher, I frequently felt clumsy and unsure but reminded myself of my similar experience integrating Gardner's Theory of Multiple Intelligences in my early years of teaching. Today, I represent content through multiple means without much thought and finding the resources is enjoyable. With practice, crafting a full-UDL classroom could become second nature as well. Finding a strong, supportive, and creative PLC with whom I could collaborate will make the transition to a full-UDL classroom achievable after this project and exciting to develop.

UDL provides hope for improved access to the joys of science and engineering for all learners.

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APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD ACCEPTANCE

Protocol Review Dates Report
Printed By: Dumm, Gisela
8/4/2023 4:02:53 PM

Report Comments

Protocol Number: 2023-502-EXEMPT **Reference Number:** 502 **PI** Dumm, Gisela

Submission Date	Status	Status Date
12/11/2022	Returned For Modification	1/4/2023
2/1/2023	Approved	2/6/2023

Approval Cycle Time 57
Average Sub Cycle 15

Overall Average Cycle Time 57

APPENDIX B

CELL STRUCTURE AND FUNCTION EXAM

1. Which statement is NOT part of the Cell Theory?
    a. All living things are made of cells.
    b. The cell is the basic unit of life.
    c. Cells contain small organisms within them.
    d. Cells arise from pre-existing cells.

2. In general, unicellular organisms use _____ to perform life functions and multicellular organisms use _____ to perform life functions.
    a. Organelles, organ systems
    b. Tissues, organs
    c. Organs, organ systems
    d. Organ systems, organelles

3. Which type of cells do NOT contain a nucleus?
    a. Prokaryotes
    b. Eukaryotes
    c. Animal Cells
    d. Plant Cells

4. What structure is found in BOTH prokaryotes and eukaryotes?
    a. Mitochondria
    b. Ribosomes
    c. Lysosomes
    d. Chloroplasts

5. Which type of cell always has a cell wall?
    a. Bacterium
    b. Protist
    c. Plant Cell
    d. Animal Cell

6. Which type of cell can have a flagellum or cilia?
   a. Protist
   b. Animal Cell
   c. Plant Cell
   d. Both a and b

7. Which organelle is important to making energy in a cell?
   a. Cell membrane
   b. Vacuole
   c. Ribosome
   d. Mitochondria

8. Which organelle is important to sorting and packaging substances in the cell into vesicles?
   a. Lysosomes
   b. Golgi bodies
   c. Rough ER
   d. Smooth ER

9. What is the function of ribosomes?
   a. To store food
   b. To make proteins
   c. To make lipids
   d. To contain DNA

10. Which structure allows plants to make their own food?
    a. A large central vacuole
    b. The cell wall
    c. Chloroplasts
    d. Centrioles

11. Which structure in a bacterium protects it from being “eaten” by other cells?
    a. The cell wall
    b. The cell membrane
    c. The capsule
    d. The nucleoid

12. Which structure can help a bacterium move around?
    a. Nucleoid
    b. Flagellum
    c. Ribosome
    d. Cell wall

13. What do you call the structure that is like a “mouth” to a paramecium?
    a. Food vacuole
    b. Macronucleus
    c. Contractile vacuole
    d. Oral groove

14. What is NOT a function of a cell membrane?
    a. The cell membrane protects the cell.
    b. The cell membrane controls the reading of DNA in the cell.
    c. The cell membrane controls what enters and exits the cell.
    d. The cell membrane is important to cell signaling or communication.

15. What is the main component of a cell membrane?
    a. Carbohydrates
    b. Cholesterol
    c. Phospholipids
    d. Glycoproteins

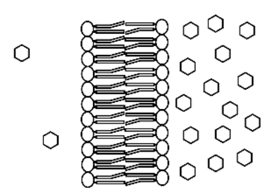
16. Transmembrane proteins can form:
    a. Channels
    b. Pumps
    c. Receptors
    d. All of the above

17. Which structure in the cell membrane often acts as an antigen?
    a. Transmembrane protein
    b. Peripheral protein
    c. Glycoprotein
    d. Cholesterol

18. Which statement below best describes the shape of a ligand and the receptor it binds?
    a. A ligand has a specific shape that matches the receptor it binds.
    b. A ligand has a non-specific shape so it can easily bind its receptor.
    c. A ligand has a specific shape that does not match the receptor it binds.
    d. A ligand has a non-specific shape so that it can change the shape of its receptor.

19. Which of the following is NOT an example of passive transport?
    a. Diffusion
    b. Facilitated Diffusion with a Channel Protein
    c. Facilitated Diffusion with a Carrier Protein
    d. Endocytosis

20. Below is a diagram that shows the concentration of a molecule inside and outside of a cell. The molecule is able to directly pass across the cell membrane. In which way will the molecules move without using any energy?

Inside the Cell  Outside the Cell

a. From outside (high concentration) to inside (low concentration)
b. From outside (low concentration) to inside (high concentration)
c. From inside (high concentration) to outside (low concentration)
d. From inside (low concentration) to outside (high concentration)

21. Active transport will transport a substance:
    a. Against the concentration gradient, from high to low concentration
    b. Against the concentration gradient, from low to high concentration
    c. Down the concentration gradient, from high to low concentration
    d. Down the concentration gradient, from low to high concentration

22. What is osmosis?
    a. The diffusion of water
    b. The active transport of water
    c. The diffusion of salts using a channel protein
    d. The diffusion of sugar using a carrier protein

23. What happens when you place an animal cell, like a red blood cell, into a highly concentration environment compared to inside the cell?
    a. The cell swells
    b. The cell shrinks
    c. Nothing happens to the cell

24. What happens to the pressure inside a plant cell when the cell is placed in a low hypotonic solution?
    a. The pressure increases
    b. The pressure decreases
    c. The pressure remains the same

25. What is the most specific type of endocytosis?
    a. Phagocytosis
    b. Pinocytosis
    c. Receptor-mediated endocytosis
    d. Facilitated diffusion

26. Which organelle is important to preparing substances that are expelled from a cell during exocytosis?
    a. Ribosomes
    b. Smooth ER
    c. Golgi bodies
    d. Mitochondria

27. Contrast the absorption of oxygen by a unicellular organism and a large multicellular organism, like a chicken. (2 points)

____

____

____

28. How could you tell an animal cell from a plant cell? (4 points)

____

____

____

29. A student observes a cell under the microscope. It appears to be a unicellular organism. It has cilia, a nucleus and chloroplasts. What type of cell is the student observing? Explain. (4 points)

____

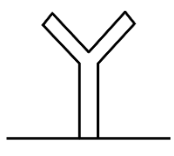
____

____

30. What is the difference between rough endoplasmic reticulum and smooth endoplasmic reticulum? (3 points)

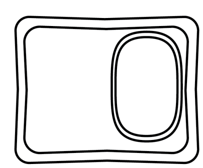
31. What could happen to a paramecium if it did not have a contractile vacuole? (2 points)

32. Below is a membrane receptor. Draw a picture of a ligand that would most likely fit into the receptor. (1 point)



33. What is the difference between passive and active transport? (4 points)

34. A plant cell was placed in a solution and observed with a microscope. After a few minutes, the cell looks like the photo below. What kind of solution was the plant cell placed in? (4 points)



APPENDIX C

INTEREST SURVEY 1

Participation is voluntary and you can choose to not answer any questions you do not want to answer and/or you can stop at any time. This will not affect your grade.

1. I would rather find out things by asking an expert than by doing an experiment.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

2. I find it boring to hear about new ideas.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

3. Science is one of the most interesting school subjects.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

4. I would rather solve a problem by doing an experiment than be told the answer.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

5. The material covered in science lessons is uninteresting.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

6. In science experiments I like to use new methods which I have not used before.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

7. It is better to ask the teacher the answer than to find it out by doing experiments.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

8. I am unwilling to change my ideas when evidence shows that the ideas are poor.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

9. I would enjoy school more if there were no science lessons.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

10. In science experiments, I report unexpected results as well as expected ones.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

11. I dislike listening to other people's opinions.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

12. I look forward to science lessons.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

APPENDIX D

APPLICATION CARD

Part I: Remember

List all the topics you remember from class and lab this week.

Part II: Apply

Step 1

Circle one of the above topics and apply it to a new science or engineering fair project. Brainstorm below before finalizing in Step 2.

Step 2

If you applied the topic to a science fair project, identify

- Hypothesis

- Manipulated Variable
- Responding Variable
- At Least Three Relevant Constants

If you applied the topic to an engineering fair project, identify

- What is the problem you are trying to solve?

- What do you need to know before you start?

- What are some problems you can imagine now?

APPENDIX E

HUMAN TABLEAU RUBRIC

Human Tableau Assessment

Student Names: ____________________________________

CATEGORY	4	3	2	1
Preparedness	Group is completely prepared and has obviously rehearsed.	Group is fairly prepared but could have used more rehearsals.	Group is somewhat prepared, but it is clear that rehearsal was lacking.	Group does not seem at all prepared to present.
Content	Presentation shows a full understanding of the topic.	Presentation shows a good understanding of the topic.	Presentation shows a good understanding of parts of the topic.	Presentation highlights the group does not seem to understand the topic very well.
Collaboration with Peers	Group behaves respectfully, stays on task, shares ideas, and supports the efforts of the group. Group makes a strong effort to keep people working together.	Group behaves respectfully and is usually on task. Group makes an effort to keep working together.	Group behaves respectfully and is sometimes on task. There is some effort to work together, but many times, students are off-task or having side or unrelated conversations.	Very little group cohesion, respect, or on-task behavior.
Props	Many props are used (could include costume) that show considerable work/creativity and which make the presentation better.	Some props are used that show work/creativity and which make the presentation better.	One or two props are used which make the presentation better.	No props OR the props chosen detract from the presentation.

Teacher Comments

APPENDIX F

UNIT POSTTREATMENT INTERVIEW

Participation is voluntary and you can choose to not answer any questions you do not want to answer and/or you can stop at any time. This will not affect your grade.

Cell Structure and Function Unit

1. What did you like about how the content of this unit was presented?

2. What did you dislike about how the content of this unit was presented?

3. What did you like about how you were tested upon your knowledge?

4. What did you dislike about how you were tested upon your knowledge?

5. Did this unit change your experience or perception of science? Explain.

Participation is voluntary and you can choose to not answer any questions you do not want to answer and/or you can stop at any time. This will not affect your grade.

Organization of the Body Unit

1. What did you like about how the content of this unit was presented?

2. What did you dislike about how the content of this unit was presented?

3. What did you like about how you were tested upon your knowledge?

4. What did you dislike about how you were tested upon your knowledge?

5. Did this unit change your experience or perception of science? Explain.

APPENDIX G

ORGANIZATION OF THE BODY EXAM

1. What part of the body is most important to observing the natural world and to communication with other people?
    a. The face
    b. The neck
    c. The chest
    d. The legs

2. Which part of the body connects the arms to the rest of the body?
    a. The chest
    b. The shoulders
    c. The neck
    d. The hips

3. Which part of the body contains the heart and lungs?
    a. The head
    b. The neck
    c. The chest
    d. The abdomen

4. Which of the following lists the levels of organization from smallest (simplest) to largest (most complex)?
    a. Cell → Tissue → Organ → Organ System → Organism
    b. Cell → Organ → Tissue → Organ System → Organism
    c. Organ → Tissue → Cell → Organ System → Organism
    d. Organism → Organ → Organ System → Tissue → Cell

5. Which type of tissue regulates the exchange of substances in and out of structures, produces hormones and is important to your senses?
   a. Epithelial tissue
   b. Connective tissue
   c. Muscular tissue
   d. Nervous tissue

6. Bone is an example of:
   a. Epithelial tissue
   b. Connective tissue
   c. Muscular tissue
   d. Nervous tissue

7. Which type of tissue is specialized to react to stimuli?
   a. Epithelial tissue
   b. Connective tissue
   c. Muscular tissue
   d. Nervous tissue

8. Which body system consists of the skin, hair, nails, and oil glands?
   a. Skeletal system
   b. Muscular system
   c. Integumentary system
   d. Nervous system

9. Which system is most important to shaping, supporting, and protecting the body?
    a. Skeletal system
    b. Muscular system
    c. Nervous system
    d. Circulatory system

10. Which organ system is most important to movement?
    a. Skeletal system
    b. Muscular system
    c. Nervous system
    d. Circulatory system

11. Which system is most important to transporting nutrients and oxygen throughout the body?
    a. Respiratory system
    b. Circulatory system
    c. Nervous system
    d. Digestive system

12. Which system is most important to controlling and coordinating the body's functions?
    a. Integumentary system
    b. Circulatory system
    c. Respiratory system
    d. Nervous system

13. The lungs are important to:
    a. The nervous system
    b. The respiratory system
    c. The excretory system
    d. Both b and c

14. The urinary system, which includes the kidneys, is a “sub-system” of the:
    a. Respiratory system
    b. Excretory system
    c. Digestive system
    d. Circulatory system

15. Which organ system is made up of hormone secreting glands?
    a. Integumentary system
    b. Digestive system
    c. Endocrine system
    d. Nervous system

16. Which organ system is important to nurturing a developing offspring?
    a. Nervous system
    b. Digestive system
    c. Female reproductive system
    d. Male reproductive system

17. Which organ is most important to breathing – inhalation and exhalation?
    a. The heart
    b. The lungs
    c. The pancreas
    d. The kidneys

18. The pancreas is important because:
    a. It produces hormones that control the amount of sugar in your blood
    b. It produces hormones that control the amount of carbon dioxide in your blood
    c. It produces digestive enzymes that help digest food
    d. Both a and c

19. Which organ produces bile to help you digest fat AND filters toxins out of the blood?
    a. The lungs
    b. The kidneys
    c. The liver
    d. The pancreas

20. Which organ is like the "control center" of the entire body?
    a. The heart
    b. The brain
    c. The lungs
    d. The kidneys

21. Do unicellular organisms have organs and organ systems? Explain. (4 points)

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22. What would happen if you did not have a digestive system? (3 points)

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23. What would happen if the heart stopped beating or contracting? (3 points)

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APPENDIX H

INTEREST SURVEY 2

Participation is voluntary and you can choose to not answer any questions you do not want to answer and/or you can stop at any time. This will not affect your grade.

1. I would prefer to find out why something happens by doing an experiment rather than by being told.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

2. I enjoy reading about things which disagree with my previous ideas.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

3. Science lessons are fun.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

4. I dislike repeating experiments to check that I get the same results.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

5. School should have more science lessons each week.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

6. I would rather agree with other people than do an experiment to find out for myself.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

7. I am curious about the world in which we live.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

8. ~~I would rather agree with other people than do an experiment to find out for myself.~~

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

9. Finding out about new things is unimportant.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

10. I like to listen to people whose opinions are different from mine.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

11. Science lessons are a waste of time.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

12. It is better to be told scientific facts than to find them out from experiments.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
o	o	o	o	o

APPENDIX I

S&E FAIR: SCIENCE RUBRIC

Science and Engineering Fair: Science Project

Student Name: ______________________________________

CATEGORY	4	3	2	1
Idea	Independently identified a novel question which was interesting to the student and which could be investigated.	Identified, with adult or online help, a novel question which was interesting to the student and which could be investigated.	Identified, with adult or online help, a question which could be investigated.	Identified a question that could not be tested/investigated or one that did not merit investigation. Or, completed a similar project earlier.
Hypothesis Development	Independently developed an hypothesis well-substantiated by a literature review and observation of similar phenomena.	Independently developed an hypothesis somewhat substantiated by a literature review and observation of similar phenomena.	Independently developed an hypothesis somewhat substantiated by a literature review or observation of similar phenomena.	Needed adult assistance to develop an hypothesis or to do a basic literature review.
Variables	Independently identified and clearly defined the manipulated and responding variables.	Independently identified the manipulated and responding variables. Some feedback was needed to clearly define the variables.	With adult help, identified and clearly defined the manipulated and responding variables.	Adult help needed to identify and define manipulated and responding variables.
Constants	Independently identified and clearly defined any relevant constants.	Independently identified any relevant constants. Some feedback was needed to clearly define the constants.	With adult help, identified and clearly defined any relevant constants.	Adult help needed to identify any relevant constants.
Control	Independently identified and clearly defined a control.	Independently identified the control. Some feedback was needed to clearly define the control.	With adult help, identified and clearly defined the control.	Adult help needed to identify the control.
Descripton of Procedure	Procedures were outlined in a step-by-step fashion that could be followed by anyone without additional explanations. No adult help was needed to accomplish this.	Procedures were outlined in a step-by-step fashion that could be followed by anyone without additional explanations. Some adult help was needed to accomplish this.	Procedures were outlined in a step-by-step fashion, but had 1 or 2 gaps that required explanation even after adult feedback had been given.	Procedures that were outlined were incomplete or not sequential, even after adult feedback had been given.
CATEGORY	4	3	2	1
Data Collection	Data was collected several times. It was summarized, independently, in a way that clearly describes what was discovered.	Data was collected more than one time. It was summarized, independently, in a way that clearly describes what was discovered.	Data was collected more than one time. Adult assistance was needed to clearly summarize what was discovered.	Data was collected only once and adult assistance was needed to clearly summarize what was discovered.
Conclusion	Student provided a detailed conclusion clearly based on the data and related to previous research findings and the hypothesis.	Student provided a somewhat detailed conclusion clearly based on the data and related to the hypothesis.	Student provided a conclusion with some reference to the data and the hypothesis.	No conclusion was apparent OR important details were overlooked.
Diagrams	Provided an accurate, easy-to-follow diagram with labels to illustrate the procedure or the process being studied.	Provided an accurate diagram with labels to illustrate the procedure or the process being studied.	Provided an easy-to-follow diagram with labels to illustrate the procedure or process, but one key step was left out.	Did not provide a diagram OR the diagram was quite incomplete.
Display	Each element in the display had a function and clearly served to illustrate some aspect of the experiment. All items were neatly and correctly labeled.	Each element had a function and clearly served to illustrate some aspect of the experiment. Most items were neatly and correctly labeled.	Each element had a function and clearly served to illustrate some aspect of the experiment. Most items were correctly labeled.	The display seemed incomplete or chaotic with no clear plan. Many labels were missing or incorrect.

Teacher Comments

APPENDIX J

S&E FAIR: ENGINEERING RUBRIC

Science and Engineering Fair: Engineering Project

Student Name: ______________________________________

CATEGORY	4	3	2	1
Idea	Independently identified a novel problem which was interesting to the student and which could be solved.	Identified, with adult or online help, a novel problem which was interesting to the student and which could be solved.	Identified, with adult or online help, a problem which could be solved.	Identified a problem that could not be tested/investigated or one that did not merit being solved.
Idea Development	Independently defined the engineering problem to be solved, identifying the need, the target user, and the justification, fully substantiated by a literature review and comparison to similar solutions.	Independently defined the engineering problem to be solved, identifying the need, the target user, and the justification, somewhat substantiated by a literature review and comparison to similar solutions.	Somewhat Independently defined the engineering problem to be solved, identifying the need, the target user, and the justification, performing a brief literature review and comparison to similar solutions.	Needed adult assistance to define the engineering problem to be solved, do a literature review, and identify the need, the target user, and the justification. There is no comparison to similar solutions.
Variables	Independently identified and clearly defined specified design requirements that state the important characteristics the solution must meet while keeping the target user in mind when identifying the requirements.	Independently identified and defined specified design requirements while keeping the target user in mind when identifying the requirements. Some feedback was needed to clearly define the design.	With adult help, identified and defined specified design requirements while keeping the target user in mind when identifying the requirements.	Adult help needed to identify and define specified design requirements.
Alternatives	Independently identified and chose the best solution from the alternatives, justifying how the solution meets the design requirements.	Independently identified and chose the best solution from the alternatives. Some feedback was needed to meet the design requirements.	With adult help, developed, identified and chose the best solution from the alternatives.	Adult help needed to develop and select alternatives.
Prototype Development	Independently developed the solution, refining and improving it during the construction of a prototype.	Independently developed the prototype. Some feedback was needed to construct it.	With adult help, developed the prototype and constructed it.	No prototype constructed
CATEGORY	4	3	2	1
Prototype Testing	Used information collected during the testing of the prototype to improve the product. Redesigned and retested the product until the design goal and design requirements were met No adult help was needed to accomplish this.	Used information collected during the testing of the prototype to improve the product. Some adult help was needed to accomplish this.	Used some information collected during the testing of the prototype propose alterations to the product but did not rebuild.	Prototype not tested.
Data Collection	Included a clear visual representation of data collected/observations made. It was summarized, independently, in a way that clearly describes what was discovered.	Data was collected more than one time. It was summarized, independently, in a way that clearly describes what was discovered.	Data was collected more than one time. Adult assistance was needed to clearly summarize what was discovered.	Data was collected only once and adult assistance was needed to clearly summarize what was discovered.
Solution	Student's solution represents a significant improvement over existing products/solutions. The product is a creative solution to the problem.	Student's solution represents a slim improvement over existing products/solutions. The product is a somewhat creative solution to the problem.	Student's solution represents an alternative to existing products/solutions, but not an improvement.	No solution was apparent or significant details were overlooked.
Diagrams	Provided an accurate, easy-to-follow diagram with labels to illustrate the procedure or the process being studied.	Provided an accurate diagram with labels to illustrate the procedure or the process being studied.	Provided an easy-to-follow diagram with labels to illustrate the procedure or process, but one key step was left out.	Did not provide a diagram OR the diagram was quite incomplete.
Display	Each element in the display had a function and clearly served to illustrate some aspect of the experiment. All items were neatly and correctly labeled.	Each element had a function and clearly served to illustrate some aspect of the experiment. Most items were neatly and correctly labeled.	Each element had a function and clearly served to illustrate some aspect of the experiment. Most items were correctly labeled.	The display seemed incomplete or chaotic with no clear plan. Many labels were missing or incorrect.

Teacher Comments

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APPENDIX K

FAIR POSTTREATMENT INTERVIEW

Participation is voluntary and you can choose to not answer any questions you do not want to answer and/or you can stop at any time. This will not affect your grade.

Science & Engineering Fair (S&E Fair)

1. How did this year's process compare to previous year's processes?

2. What academic strengths did you exhibit this year during S&E Fair?

3. What skills do you think you improved this year during S&E Fair?

4. Did this fair change your experience or perception of science? Explain.