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Engineering and Graphic Design Interdisciplinary Collaborative Product Development: A Wheelchair-Mounted Rotating-Head-Support for a Disabled Child

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Luke is currently in his senior year at Rutgers University in New Brunswick, graduating in December 2022 with a bachelor's degree in Industrial & Systems Engineering. Throughout his time at Rutgers University, he participated in three consecutive co-op rotations with Johnson and Johnson, including roles in Product Temperature Control, Pharmaceutical Distribution Operations, and Process Automation and Advanced Analytics. This summer he will be transitioning to his fourth consecutive co-op assignment, where he will support J&J's CAR-T Manufacturing and Distribution Operations as an Industrial Engineer co-op.

Luke graduated from RVCC's Honors College in the summer of 2020 with an associate degree in Mechanical Engineering. During his time at RVCC he participated in the Authentic Engineering Experience, where he partnered with a local family and their disabled son to design and manufacture a rotating head-support that could be attached to a wheelchair.

As Luke prepares to graduate from Rutgers University in December 2022, he sets his sites on full-time opportunities focused on process improvement, optimization, and automation.

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Peter Stupak is President and Founder of the non-profit organization Main Engine Start that is dedicated to project-based learning for students of all ages to discover their passion for Science and Engineering and increase their self esteem and confidence. Prior to creating his non-profit organization, Peter was an Associate Professor of Engineering and Physics at the Raritan Valley Community College from 2014 to 2021, and before that he enjoyed a 22-year career in the fiber-optics manufacturing industry, living, and working in 7 countries. Peter's work involved him in Research and Development, Engineering and Manufacturing Management, and culminating in the construction, start-up, and operation of an optical fiber factory in Suzhou, China where he was also the Chief Technology Officer. He holds a B.S. in Chemistry and M.S. and Ph.D. in Mechanical Engineering from the University of Massachusetts at Amherst.

Engineering and Graphic Design Interdisciplinary Collaborative Product Development: A Wheelchair-Mounted Rotating-Head-Support for a Disabled Child

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Abstract:

Engineering and Graphic Design students collaborated in the Raritan Valley Community College's project-based learning "Authentic Engineering Experience" to design and fabricate a wheelchair-mounted rotating head support for a local disabled child. The rotating head support overcame the limitation of commercial fixed head supports and allowed the child to rotate his head sufficiently to more frequently activate mechanical switches, located near his head, and thereby interact with educational software. The Graphic Design students also provided input for a more "kid-friendly" aesthetic and created complete product "visual identities" and branding campaigns.

Introduction:

A collaborative interdisciplinary teaching methodology has been developed and successfully implemented at Raritan Valley Community College (RVCC) where students from the Engineering and Graphic Design programs work together to create interrelated projects under authentic industry conditions. This educational experience is replicable and moves beyond traditional pedagogy by establishing a real-time, real-world learning environment for students across disciplines.

In the present project the Engineering students were tasked with designing and implementing a rotating-head-support for a 12-year-old New Jersey boy, Dylan, who is wheelchair bound with multiple disabilities. Each Graphic Design student was tasked with developing a unique visual identity, product name, and branding campaign based on the perceived purpose and demographic of the rotating-head-support.

The project required the work of several Engineering teams over a period of two years. The key challenge was to enable the child to rotate his head, even a few millimeters, to activate electrical switches placed near his temples, thereby allowing him to interface with special educational software and communicate with his teacher. Since commercial wheelchair head-supports are stationary, the solution developed by the Engineering teams was a novel rotating-head-support.

In addition, a custom head-support shell and cushioning was developed so that the child's head was both well supported and comfortable. A hand-held 3D scanner was used to accurately capture the shape of the child's head and be the basis of the 3D printed head-support shell. A custom gel-cushion "honeycomb" structure was implemented in the shell.

The Graphic Design students met with the Engineering students periodically during the project to discuss ways to make the rotating-head-support more visually appealing to the child, using for example, color schemes, illustrated fabrics, and accessories such as flags with age-specific themes and images. During the final presentation of the visual identities and branding campaigns, the Engineering students participated as judges for the Graphic Design students.

This collaborative, interdisciplinary approach to project-based learning ensured that the creative process was experiential - principles and skills were employed first-hand with a primary emphasis on learning by doing, including trial and error. Students learned an array of vital skills while adding a unique cross-disciplinary collaborative experience to their education, making them better equipped for future classroom success and professional opportunities.

The spirit of this project is aligned with previous and on-going efforts to expose and engage students in “authentic” engineering experiences and environments through, for example, Hands-on projects and Project Based Learning [1-8].

Voice of the Customer:

The principal “Customer” was 12-year-old “Dylan”, a New Jersey boy who is wheelchair bound and with multiple disabilities. The project began with several initial visits of the student Team to meet Dylan and obtain input from Dylan’s Parents, Teacher, Nurse, Physical Therapist, and Occupational Therapist.

Dylan’s wheelchair was already equipped with small mechanical switches that were placed near the temples on his head. The idea was that small rotations of Dylan’s head made physical contact between his head and one of the switches. By activating either the switch on the left or right of his head, Dylan made corresponding choices, through a special software interface, of “Yes” or “No” and selections of objects on the screen. In this manner Dylan, working with his teacher, would be able to make progress for his education, communication, and enjoy on-screen interactive entertainment. However, commercially available wheelchair headrests are mechanically fixed and therefore restrict the rotation of the head. Dylan’s condition did not allow him to easily overcome these restrictions making it difficult for him to activate the switches. Therefore, his interaction with the software was inhibited.

Two key tasks were defined for the student Team. One task was to develop a rotating head support that would allow Dylan to easily rotate his head, even only the few millimeters needed to activate the switches near his temples, without the mechanical restrictions of a typical stationary wheelchair-mounted head support. The other task was to develop a custom head support shell and cushion that would support Dylan’s head while being comfortable and easy to maintain. Typical commercial head supports are not conformant to the details of the shape of the head of the user and use closed-cell foam that crushes after continued use and fabric covers that may not be easy to remove or maintain.

Principle of Operation:

The design of the rotating head support evolved through multiple iterations during the project. Each iteration was tested with Dylan’s collaboration and critical feedback was given by Dylan’s Parents, Teacher, and the Occupational and Physical Therapists.

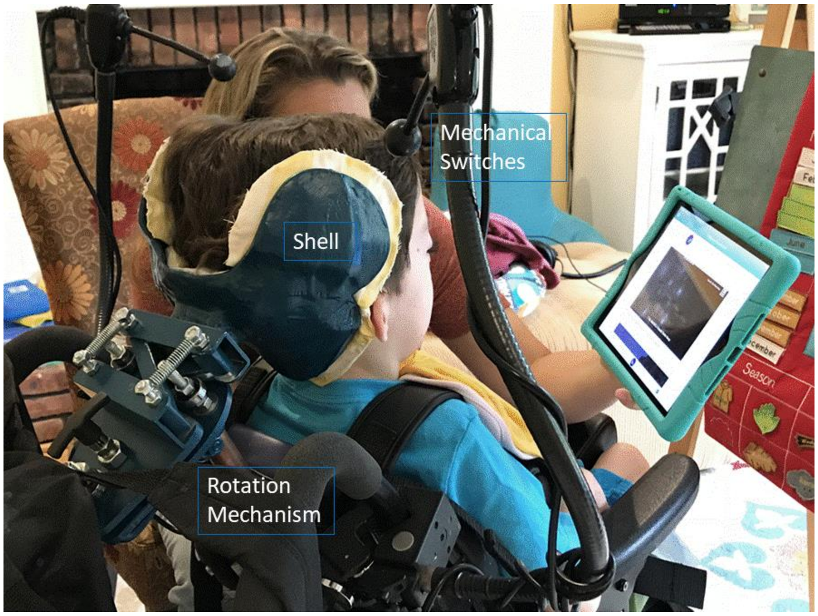

Figure 1: An intermediate version of the rotating head support being used by the Student Team's Customer, "Dylan". Visible in the photo is Dylan using the prototype with his Teacher, the rotation mechanism in the lower left, the head support shell, and the mechanical switches near Dylan's head.

The final design of the rotation mechanism was based on two intersecting "circles" of rotational motion (Figure 2). The center of one of the "circles" was the mechanical bearing and support components attached to the wheelchair, and the center of the second "circle" was the vertebrae of Dylan's neck. The two "circles" touched in principle only at one point on their circumference. With this novel design, the head rotated purely about its center and therefore did not require any translation of the head and the extra effort required to do so. Only the slightest torque was required to rotate the head.

Mechanical Design:

To realize the concept of the intersecting "circles" of rotational motion, the mechanical design required three main elements: 1) the components defining one "circle" of rotation to be anchored to a platform attached to the wheelchair, 2) the components of the second "circle", including the head-support shell and cushion, to be freely floating, and 3) a way to connect the two "circles".

The components comprising the "circle" attached to the wheelchair consisted of a "foundation" platform, made from an aluminum plate, attached to a post that fit securely into existing commercial hardware mounted to the back of the wheelchair. A second "rotating" aluminum plate was attached to the first plate by using a thrust-bearing located at one end of the plate. The thrust bearing allowed a low-torque in-plane rotation of the "rotating" plate and at the same time a substantial and rigid mechanical support to resist out-of-plane deflection. An aluminum channel section was mounted to the opposite end of the "rotating" plate. The result was that the motion of the "rotating" plate around the thrust bearing formed the first "circle" of motion of the design (Figure 3).

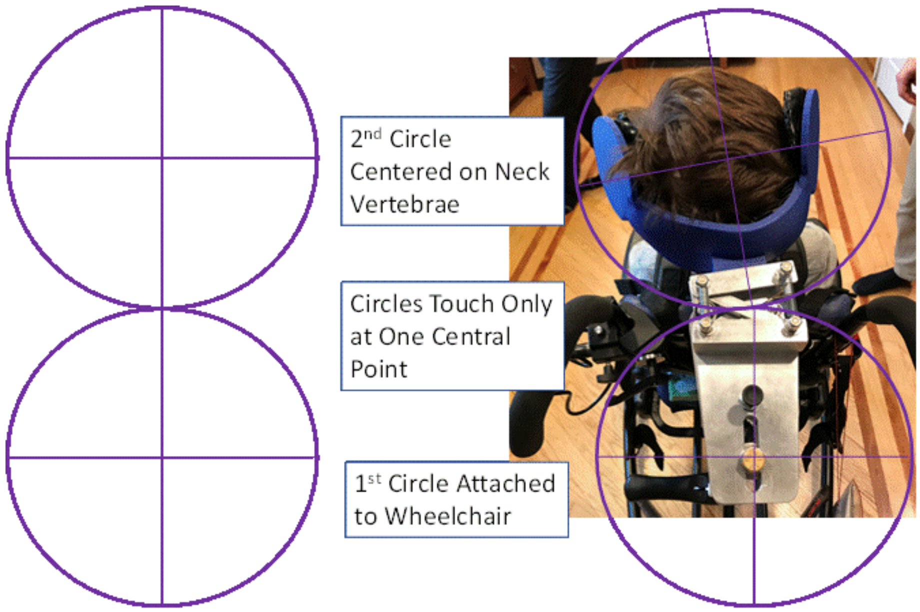

Figure 2: The principle of the rotating head support was two intersecting circles of rotation. The left sketch shows the lower 1st circle which is attached to the wheelchair through a thrust bearing. The upper 2nd circle is centered on Dylan's neck vertebrae. The right photo is a top view of the rotating head support being used by Dylan and the 1st and 2nd circles superimposed on the image. The circles intersect at one point in the middle of the "Crossed Bars" in the center of the right photo.

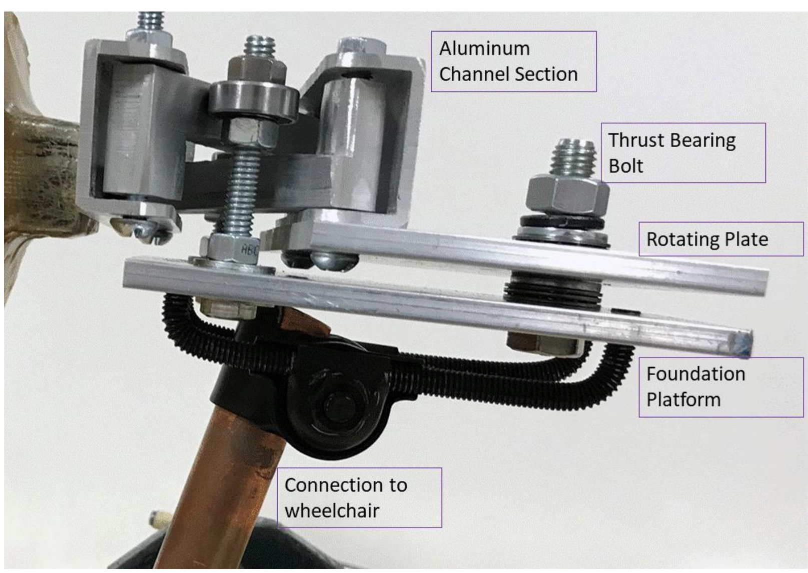

Figure 3: Side view photo of an early version of the rotating head support mechanism with the components comprising the 1st Circle of rotation annotated.

The creation of the second “circle” of motion, containing the head-support shell and cushion, was made by using a “crossed” 4-bar linkage. The first “bar” of the “crossed” 4-bar linkage was the aluminum channel section attached to the “rotating” aluminum plate. A second aluminum channel section was attached to the back of the head-support shell. The two “crossed” bars served to mechanically connect the “rotating” aluminum plate to the head-support shell. Therefore, the head-support shell was cantilevered and entirely mechanically supported from the thrust bearing.

To cause the simultaneous rotational motion of both “circles”, bearings were added to contact the “crossed” bars to constrain and guide their motion. The bearings were mounted on posts that were attached to the “foundation” plate. In practice, for example, if a small torque applied to the head support shell causes a clockwise rotation of the shell, then a counterclockwise rotation of the “rotating” plate on the opposite side of the “crossed” bars would result. In the absence of the bearings, the entire cantilever would simply rotate about the thrust bearing. In this manner, the two “circles” of rotational motion were achieved (Figure 4).

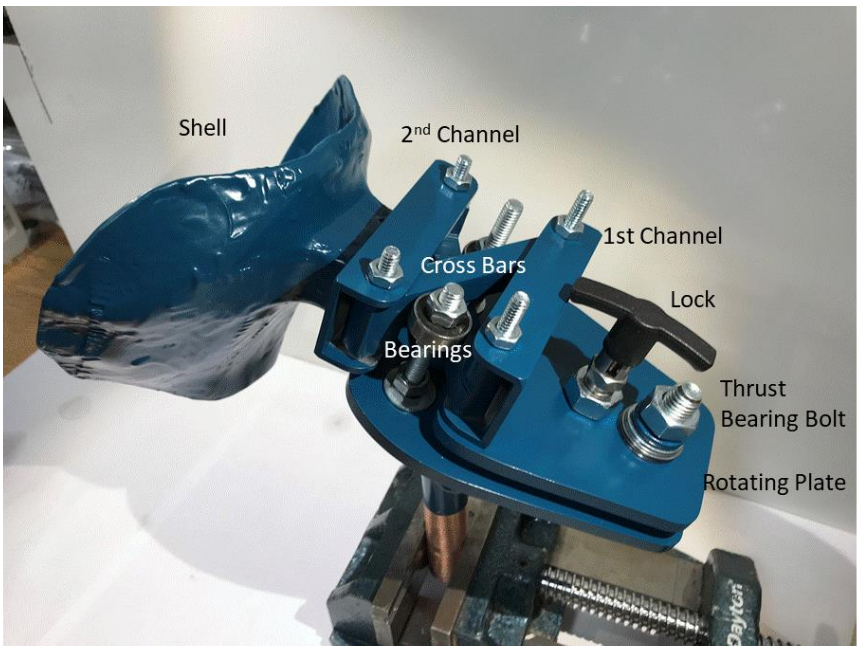

Figure 4: A photo of an intermediate version of the rotating head support with the “Cross Bars” and two “Channel” sections forming the “Crossed” 4-bar linkage and the bearings attached to posts and anchored into the Foundation Plate. The head support shell is the hand-layup of glass-fiber mesh and epoxy type. This version was made using simple machines and hand tools.

To minimize the force needed to be applied by the user to rotate the head-support shell, the radius of the two “circles” of motion were made as large as possible to form a long “lever-arm”. However, since the radii of the circles of motion corresponded to the distance from the center of the thrust bearing to the center of the “crossed” bars (and the neck vertebrae to the center of the “crossed” bars), the radius size was limited to the extent that the cantilevered head-support shell was still well supported by the thrust bearing with a minimum out-of-plane deflection.

The center of the “crossed” bars corresponded to the point where the two “circles” of motion touched (Figure 2). The length of the “crossed” bars were made as short as possible to better approximate a tangential transfer of the torque from the “circle” of motion of the user’s head to the “circle” of motion of the “rotating” plate attached to the thrust bearing.

Additionally, tension springs were added to the “crossed” bars to automatically mechanically “center” the head-support shell and a “locking” mechanism was added so that the head-support shell could be locked in place when Dylan was being placed into the wheelchair (Figure 5).

The initial versions of the mechanical design were made using simple shop tools – bandsaw, drill press, sander, and hand tools. This allowed the maximum freedom for exploring design options but resulted in less polished prototypes. The final design version was properly drawn in CAD by the student Team and then machined using the services of the on-campus “Advanced Manufacturing” program’s Machine Shop and staff. Also, all rotating connections of the final design used bearings to minimize the friction and improve durability of the components.

Therefore, this novel design provides the user with a fully natural and free rotation about their neck vertebrae with a minimum of required torque while also providing support to their head through the cantilevered head-support shell.

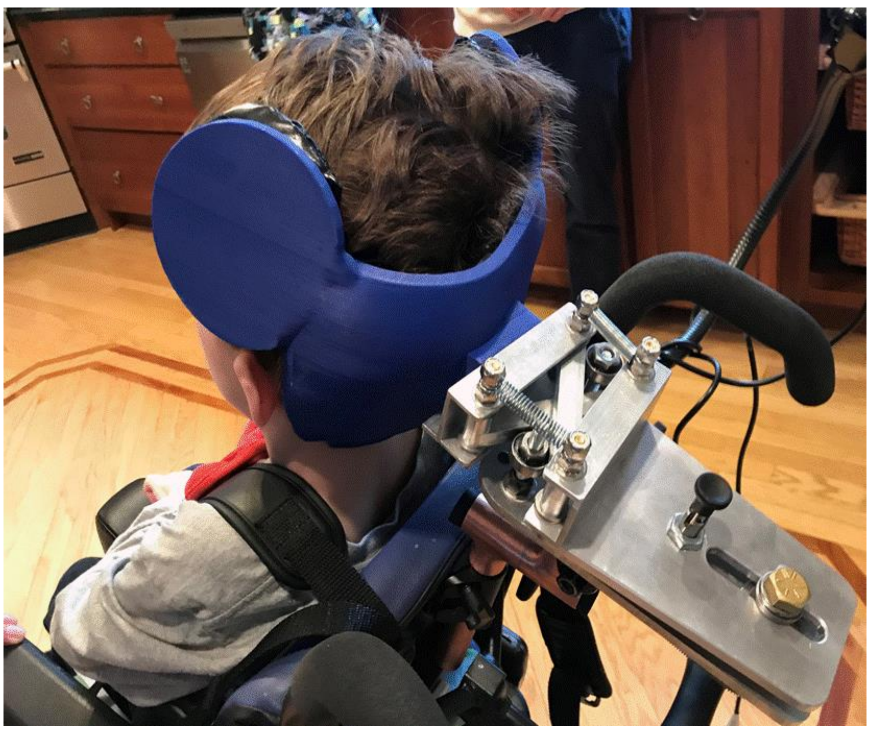

Figure 5: The final version of the rotating head support being used by Dylan. This final design version was made using properly drawn and machined mechanical components and 3D laser-scanned and 3D printed head support shell.

Head-Support Shell Design and Process:

The requirements for the head-support shell were that it be light weight, rigid, and customizable to match the shape of the Dylan's head. The first versions of the shell used a hand-layup of glass-fiber mesh in an epoxy matrix (Figure 5). Multiple attempts were made by the student Team to reproduce the shape of Dylan's head by using quick-setting plaster placed over a plastic wrap applied to the back of Dylan's head. It was necessary that the process require only a few minutes to avoid Dylan becoming uncomfortable. These tests resulted in faithful plaster molds of the head shape. To be useful, however, the plaster molds were later lined with plastic wrap and additional plaster was added to create a "negative" mold. Finally, the "negative" mold was again covered in plastic wrap and the glass-fiber mesh and epoxy matrix was added to make the final head-support shell. A mounting plate used for attaching the head-support to the aluminum channel section of the 4-bar linkage was also embedded in the epoxy matrix. These shells were fully customizable and functional but were very labor intensive.

Through the generosity of a Donor, a 3D Laser Scanning system was later purchased (EinScan Pro 2X Scanner and Solid Edge Shining 3D OEM Edition software) allowing the free-space, non-contact, three-dimensional scan of Dylan's head. The objective was to use the Laser Scanning data to 3D Print (Ultimaker S5 3D Printer and Ultimaker Cura software) the head-support shell, thereby eliminating the plaster molds and glass-epoxy hand layup.

The student Team developed a process to apply a spandex elastic cloth to the back of Dylan's head to flatten his hair and allow the laser mapping of the contours of his head. A "dry shampoo" applied to the spandex cloth was effective in reducing glare and reducing 3D Scanning errors. Again, the process was developed to require only a few minutes of Dylan's participation to avoid discomfort.

The 3D Laser Scanning system produced a "point cloud" of three-dimensional surface contour data of the head. The "point cloud" was transformed into an editable and 3D printable computer file by processing it through a free on-line software (Meshmixer). Solidworks was used to design the lateral-support side "ears" for the head support shell and the mounting block to attach the head support shell to the channel section. The Solidworks files were imported into Meshmixer and added to the 3D Scan. Considerable effort was required to learn the process of editing and preparing the file to print. But the result was a faithful computer model of Dylan's head that could be used for multiple iterations of the head-support shell (Figure 6).

The final version of the 3D Printed head support shell, with the lateral-support "ears" is shown in Figure 5.

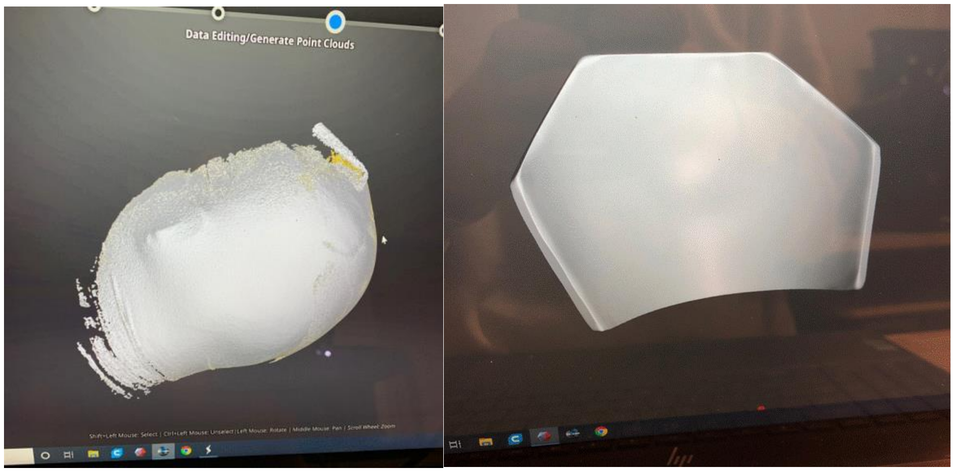

Figure 6: Screen photos of the “Head Support Shell” produced from the 3D Scanner. The left photo is the unedited “Point Cloud” and the right photo was edited and processed in Meshmixer.

Cushion Design and Fabrication:

The requirements of the cushion lining the inside surface of the head-support shell was that it be soft, comfortable, maintain its compliant mechanical properties over long time frames, and that a fabric covering would be used that would be comfortable in both humid and dry conditions and be easily removed and cleaned.

Commercially available head-support cushions often use closed-cell polymer foam that tends to crush over time with use and thereby lose it’s compliant cushioning properties. Instead, the student Team selected a soft rubber “gel” material used for motorcycle seats. The rubber “gel” was soft and maintained its mechanical properties over time and was easy to apply to the head-support shell. However, when used as a single sheet, it was still too stiff to feel comfortable for long periods of time.

To overcome this problem, the student Teams borrowed concepts from cellular materials, for example honeycombs and patterned-foam mattress materials, and learned through trial and error how to tailor the compliance of the cushion by cutting the “gel” into structural elements and using them together. For example, initial work focused on cutting rectangular strips of the “gel” and applying them to the head-support shell leaving a gap of several millimeters between the strips. Since rubber maintains its volume under compression, the presence of the small gaps between the strips allowed room for the “gel” material to expand laterally when compressed in the head-support shell resulting in a significantly softer and more compliant cushion. The main issue with this approach was the labor of gluing the individual rectangular strips to the head-support shell.

In the final design, Dylan’s Parents chose a layered composite with a lower layer of the rubber gel cut into a “honeycomb” pattern using a cookie-cutter and an upper layer of 1/8” thick gel rubber sheet (Figure 7). The design felt compliant and comfortable for long periods and maintained its compliant properties after extended use. Also, the 1/8” gel rubber layer resulted in a smooth feeling without sensing the honeycomb structure beneath. This closely spaced diamond-shaped holes were cut into the “gel” material to mimic the lateral expansion performance of the rectangular strips while maintaining a single piece of "gel" to be applied to the head-support shell.

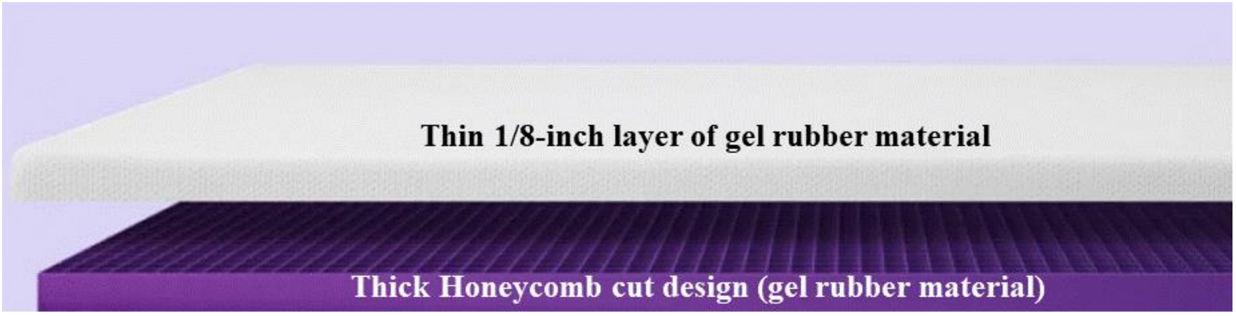

Figure 7: Representation of the final cushion material design used in the head support shell.

Graphic Design Team Visual Identities:

The Graphic Design student Team interacted with the Engineering student Team in two main ways through the project.

First the two Teams met periodically during to discuss ways to make the rotating-head-support more visually appealing to the child. For example, the color schemes of the 3D printed head-support and cushion covering were coordinated, and novelty "Batman" graphic cushion coverings were used (Figure 8). Other ideas included using accessories such as flags attached to the head-support shell with age-specific themes and images.

Figure 8: An example of the novel "Kid-Friendly" cushion coverings suggested by the collaboration between the Engineering and the Graphic Design Teams.

Second, the Graphic Design Team members were individually tasked to develop a unique graphic identity and the roots of a branding campaign through supplementary components including print advertisements, stickers, and a realized package design for the product. The complete design strategies were based on each student's unique name for the product and envisioned target market. The design objectives were predicated on the novelty of the name, consistency across the visual identity (through use of the logo, color, typography, and individual compositions), and the uniqueness and functionality of the print advertisements and package design intended for marketing, distribution, and sale. During the final presentation of the visual identities and branding campaigns, the Engineering students participated as judges for the Graphic Design students. Examples of the Graphic Design Team "visual identities" are shown in Figure 9.

Assessment and Conclusion:

The assessment of the project success was viewed from two perspectives. The first was that Dylan's Parents and Teacher reported that when Dylan used the rotating head support, he was more frequently able to activate the switches located near his temples and more effectively interact with the special educational software.

Figure 9: An example of the Graphic Design student's work to develop a unique visual identity, product name, and branding campaign.

Unfortunately, given the environment of Dylan's teaching and learning environment, it was not possible to quantify the increase in the instances when Dylan's activated the switches.

The second was that the responsibility of designing and delivering a real product to a real customer, and under authentic engineering conditions, was effective in accelerating learning of important skills that are often acquired later when employed in Industry and provided the students with a real-world and hands-on story to relate to future employers.

For example, the student Teams met with Dylan's Parents, Teacher, Nurse, Physical Therapist, and Occupational Therapist multiple times throughout the project. The student Team incorporated the Customer feedback into their subsequent design and fabrication planning. While the student Team met formally with a faculty "Manager" for a formal Weekly Meeting, the overwhelming emphasis was for the student Team to reach their own designs, experience their own failures and successes in earning their own know-how, resolve their own communications and scheduling conflicts, and to respond to customer critical comments of prototype product performance. The students rotated both the Team leadership and the project planning on a weekly basis to give each member multiple opportunities for experiencing how a project is managed.

The collaboration of the Engineering and Graphics Design students was an exciting opportunity to share expertise and perspectives. This particular project is one of several [1,3] where the collaboration yielded a final result that was substantially better, because of the collaboration, than had either the Engineering or Graphics Design students had conducted the project on their own. This is an important lesson for the students as they move towards a professional life, where they will enter knowing that collaboration yields richer solutions that better satisfy their customers.

Additionally, the success of the rotating head support captured the attention of a local School and Hospital for disabled children. A collaboration was formalized just before the COVID-19 pandemic which will enable future student Teams to customize the rotating head support for individual disabled children at the facility. All rotating head supports will be given free of charge thanks to the generosity of Donors to pay for the material costs.

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