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Basic Vision Research with Clinical Applications and Science Education Assessments

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BASIC VISION RESEARCH WITH CLINICAL APPLICATIONS AND SCIENCE EDUCATION ASSESSMENTS

By

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By Andrew Wilson

Thesis Advisor: Dr. Leonard Kass

An Abstract of the Thesis Presented
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Visual Acuity (VA) examinations are one of the most commonly conducted medical assessment throughout the world. Recent advances in computer technology allows for new forms of visual assessment to be conducted. In Part I of this thesis I demonstrate the capability of an automated computer program named VISION to assess human visual acuities. Different color combinations of an object against a background emitted from a computer screen are used to examine a variety of human color vision acuities. Results indicated a significant difference in acuity scores between human subjects tested with these different color combinations. A single human subject exhibits differences in their visual acuities obtained from different combinations of emitted colors that is almost unique to that specific subject.

In Part II of this thesis, I assess the characteristics and effectiveness of incorporating these VISION programmed studies in satisfying the Capstone course requirement at the University of Maine using the Course-based Undergraduate Research Experience (CURE) assessment and interviews. In doing so, I propose a new theoretical set of guidelines for assessing all science-related Capstone experiences at any school and college.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Leonard Kass, for his help in this research and the support with the process of writing a thesis. I would also like to thank the VISION team for their work on these experiments, especially (Amanda Laverdiere, Anne Yu, Kaitlin Clark, and many more). I would also like to thank our programmers, Mike Murphy and David McNulty for helping program the Open-Door VISION program and fix any problems faced. Finally, I would like to thank my committee for their input and support throughout this process.

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1.1 Introduction and Background on the Human Visual System:

The human eye is made of many complex structures that work synergistically to send information to the brain for further processing. When light first enters the eye, it moves through the cornea, which is a transparent external layer that covers both the pupil (allows light to enter eye) and iris (circular muscle that controls the size of the pupil). The white portion of the eye, called the sclera, is continuous with the cornea and creates a supportive wall for the eye. As light moves through the eye it will travel through three different chambers filled with fluid. The first two chambers contain aqueous humor, while the last chamber contains vitreous humor. After light travels through these components and fluids of the eye, it reaches the retina. The retina is the light sensitive layer of the eye and will be described below.

The retina is a highly-organized structure in the back of the eye. There are several different layers within the human retina that contain different specialized classes of neurons. Ganglion cells, amacrine cells, interplexiform cells, bipolar cells, horizontal cells, rods, and cones constitute this specialized class of neurons. The functions of rods and cones will be discussed about in the next section. After light is received and transduced by the cones and rods, glutamate is used to excite the bipolar cells within the outer plexiform layer. Horizontal cells sit within this area and help modulate the synaptic transmission between the photoreceptors and bipolar cells [1]. Bipolar cells are specialized into two categories; rod and cone bipolar cells. Bipolar cells also divide into two subcategories called ON and OFF bipolar cells. This allows for changes in luminance or light intensity to be observed. Bipolar cells that are considered OFF, hyperpolarize in changes in light intensity, while ON bipolar cells depolarize [2]. Rod bipolar cells only consist of the OFF category,

while cone bipolar cells can be either ON or OFF. Through the inner nuclear layer and into the outer plexiform layer, processes of interplexiform cells make numerous conventional synapses upon rod and cone bipolar cell bodies and apical dendrites [3]. Cone bipolar cells meet amacrine cells and ganglion cells within the inner plexiform layer (IPL). These ganglion cells receive visual information from the photoreceptors via the bipolar cells. Ganglion cells are excited through two different pathways involving amacrine cells. The first pathway through amacrine cells is a feedforward inhibition or through the second pathway through feedback inhibition [2]. The major inhibition of these ganglion cells is mediated by GABA and glycine neurotransmitters. The ganglion cells gain information about two different opposing color schemes. The first color scheme is red vs. green, while the second scheme is blue vs. yellow. These ON/OFF color schemes are represented in Figure 1.1. The axons from the ganglion cells come together to create the optic nerve, which leaves the retina and connects with the brain for higher processing. The electrical signal moving through these different specialized neurons must first be created by the photoreceptors within the retina.

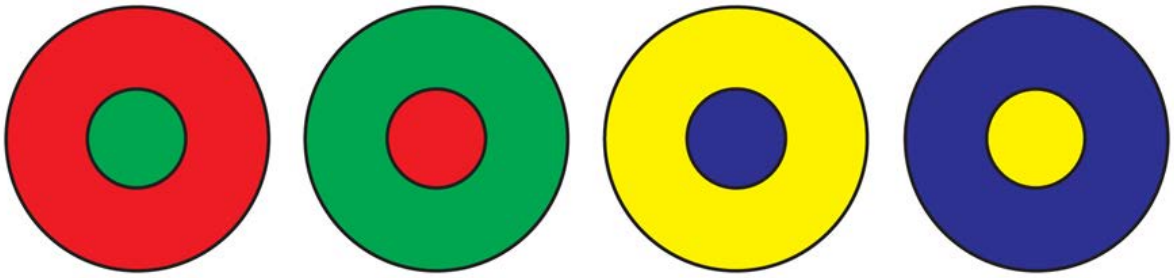


Figure 1.1: Representation of the four known types of ON/OFF color combinations assessed within the ganglion cell layer of the human eye (modified from https://mpsapsiblog.wordpress.com/2015/10/).

Photoreceptors (Rods and Cones) are the main component in the process of phototransduction. Phototransduction is conversion of light into electrical currents and signals [4]. The two photoreceptors responsible for this conversion process are shown in Figure 1.4. Rods are

extremely sensitive photoreceptors, which can detect a single photon [5], and mediate twilight and vision at low light intensities. Cones are less sensitive to light compared to rods. However, they are most sensitive in certain wavelength regions of the visible light spectrum. Due to their less sensitivity, cones are activated in bright-or day light and give primates their highest acuity vision.

As previously stated, cones are important in the function of color vision, which was previously stated. There are three types of cones that are sensitive to different wavelengths of light. The three distinct types of cones are S-, M- and L- cones that are most sensitive to blue, green and red light respectively. Rods and cones differ in the opsin that is contained within their cells. The three different opsins in the cone receptors are S-opsin, M- opsin and L-opsin. The differences in opsins are in the sequences of their amino acids compared to the other opsin molecules. This is how certain types of color deficiencies can arise. Due to a genetic mutation, there can be a loss of a certain visual pigment needed by the cones and without this pigment the person will not be able to see those colors. Cones do not have as many visual pigments compared to rod receptors. It therefore takes more light to excite cones than rods. The organization and relative numbers between the various cones and rods differ throughout the human population.

The organization and relative numbers of cones within the human fovea also varies across individuals. A study conducted provided a visualization of different cone mosaics within the periphery of the fovea [6]. Figure 1.2 shows us the immense diversity of cone mosaics throughout the population.

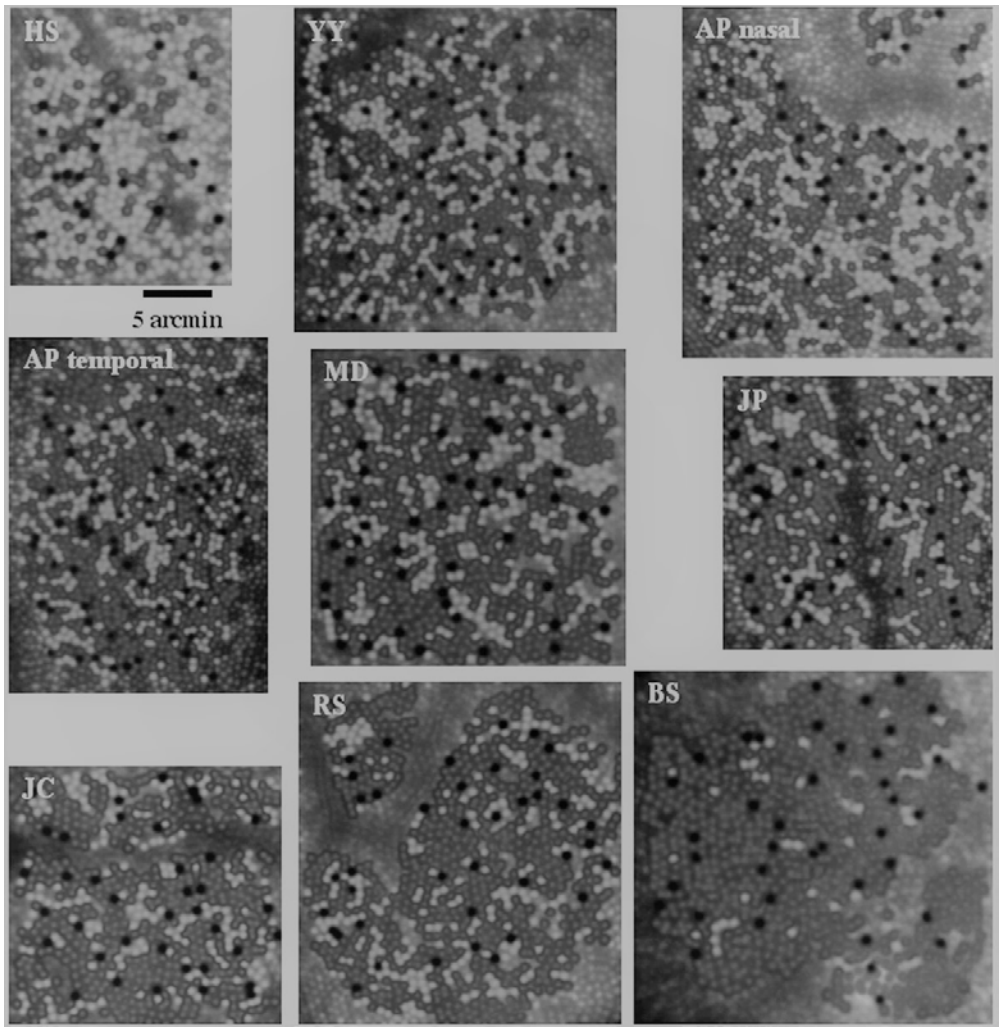


Figure 1.2: Fake-color images of cone mosaics within the peripheral fovea in different individuals. Black dots= S-cones, Dark Grey= L-cones, Light Grey= M-cones. Images taken from Hofer et al. 2005.

Even though there is a wide variation within the human population in terms of peripheral cones mosaics, the central fovea contains only L- and M- cones. This can be seen within a Figure 1.3.

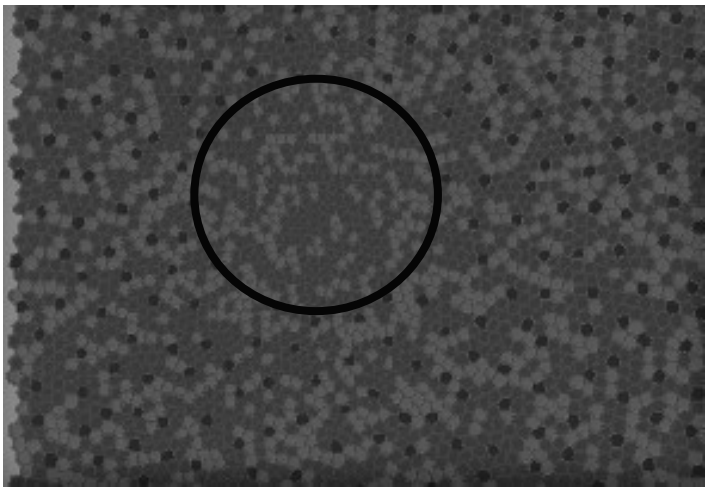


Figure 1.3: Representation of cone mosaic with central fovea. Within the center fovea (circle) there are no S-cone (Black dots). Images taken from Hofer et al. 2005.

The ganglion cells come together to form the optic nerve and there run into the brain and carry the electrical signals formed by the rod and cone receptors. The optic nerve projects primarily to the first area of visual processing named the dorsal lateral geniculate nucleus (LGN) contained within the thalamus. The LGN contains three different areas known as the parvocellular, magnocellular, and koniocellular layers. The parvocellular pathway (P-cells) have been found to receive information that opposes signals between the L- and M- cones (midget ganglion cells) [7]. P-cells contain receptive fields just like that of ganglion cells within the retina. Since the P-cells receive inputs from L- and M- cones, it is believed that this pathway in the LGN is important for red-green color vision. S-ON neurons follow a different pathway within the LGN compared to the P-pathway. The S-cones go through the koniocellular pathway within the LGN [8].

The LGN then projects extensions different layers within the primary visual cortex (VI). There has been large debate between the role of neurons within VI in terms of color perception since 5-10% of neurons respond to chromatic stimuli, while little respond to achromatic stimuli [9]. VI contains receptive fields that are much larger compared to the LGN. Approximately 10%

of these neurons show color-opponent L- and M- inputs. S-cones have much less input compared to their partner cone inputs [10]. It has been found that early on within VI S-cone inputs spread rapidly, however there is uncertainty it what role this plays. Finally, S-cone receptive fields have low proportions within the cortex like that of the LGN. Other areas within the visual cortex have been considered for color vision.

Recent studies have shown that area V2 has neurons that prefer certain colors, depending on the surrounding context [9]. V4 within macaque monkeys have provided special interest in this area for color vision. Some humans who have lesions within the ventromedial occipital lobe have impaired color vision [11] and fMRI studies have shown increase activity with chromatic stimuli [12]. There is still controversy on exactly how color perception is interpreted within the brain.

There are many visual conditions that can affect a person's high acuity center within the fovea. Refractive errors are caused by a problem with the eye to focus the image onto the retina. Examples of these are myopia (short-sightedness) and hyperopia (far-sightedness) where there is a spread of the image laterally [13]. These different refractive errors cause a change in the point spread function of the eye that leads to a decrease in the ability in many visual tasks discerning sharp edges. Myopia is when the visual system is said to be to strong and the image forms in front of the retina and hyperopia is when the visual system is not strong enough and the image forms behind the retina.

Another factor that affects the visual acuity of a person is the size of the pupil. The pupil is the main component of the eye that leads to resolution on the retina. With a large pupil, there is a large stimulation due to the amount of light and there is a decrease in diffraction, but there is also an effect on the resolution of the eye while a small pupil will have the opposite effect. The optimal

size for a pupil will be between 3 mm to 5 mm that will compromise between diffraction and resolution [14].

Contrast sensitivity is also a crucial factor when it comes to vision. In clinical settings, they use high contrast where there are black letters on a white background. However, in many instances during normal life situations we do not see such a sharp contrast. To determine the relationship between visual acuity and contrast many researchers use gratings to determine the sensitivity of the visual system as a function of grating size [13]

Finally, different genetic variations can affect the ability for individuals to determine assorted colors. The genes that constitute the pigment for L- and M- cones are located on the X-chromosome, and the gene specifying the S-cone is located on the 7^{th} chromosome. Color deficiency is a sex-linked characteristic that affects ~8% of the male population, and <1% of the female population [15]. Studies have also shown that ~15% of women are carriers for the abnormal L-/M- cone chromosome. However, recent discoveries have shown that a color deficient species may have advantages towards foraging in low light conditions [16]. It was also found that dichromats could detect color-camouflage objects better than trichromats [17]. Therefore, individuals with a color deficiency may have advantages over their trichromatic counterparts.

Visual Acuity examinations are one of the most commonly practiced tests performed in a clinical setting. Visual Acuity is defined by the sharpness of vision, which is measured by using letters or numbers at a fixed distance. There have been numerous kinds of assessments created throughout the years to test human visual acuity. The original chart created in 1862, is known as the Snellen Chart. Overtime, these charts have been changed to assess the human eye more efficiently and accurately. Some of the charts used to date are the Early Treatment Diabetic Retinopathy Study (ETDRS) Chart and the Landolt C. The Snellen and ETDRS Charts are a form

of recognition based visual acuity, since you are recognizing a letter or number. However, there is another way to assess visual acuity, and this is through resolution based tasks. An example of this is the Landolt C, where the patient must identify a gap in a circle on one of the four sides. These charts are important for the assessment of the human eye, however with the advancement of technology, can these tasks be assess using computers? This study investigates the ability to used visual display technology (VDT) to assess human visual acuity. This study also investigates what happens to the subject's ability to discern small details when different color combinations are introduced (color acuity) in the foreground color with relation to its background color.

1.2. Methods

1.2.1 Subjects

The subjects for the "Open-Door" experiments were either undergraduate or graduate student volunteers from the University of Maine whose ages ranged from 18 to 24 years.

1.2.2 Pre-examinations

Once the subjects arrived they were asked to sign-in and were given a subject ID for confidentiality purposes. Next, the subjects were asked to read an informed consent form and verbally commit to volunteering for the 30-40-minute research experiments. The subjects then filled out a confidential questionnaire and were assessed for visual function and variables that might be related to their response to colored visual stimuli. The questionnaire recorded the subject responses to items concerning visual deficiencies, skin color, eye color, age, gender and other information. The pre-test consisted of an astigmatism test (grid and radial) as well as Ishihara color blindness tests. All subjects wore their corrective lenses at all times as necessary.

1.2.3 Experimental Procedure

Once the subjects completed the two pre-tests they were directed to an area where they completed the Landolt C VA task. The chart was a logarithmic Landolt C (cat No. 2210, Precision Vision, La Salle, Illinois). The Landolt C placed 13 feet (~4 meters) in front of the subjects viewed under photopic illuminations. The Landolt C chart had five different orientations of the rings on each line with a 0.1 logMAR change for each line. The subjects started on a line where they believed they would have trouble reading and would move their way down the chart from that line until they incorrectly identified more than half of the optotypes (e.g. 3 out of 5 wrong).

Next the subjects were assigned into one of the two different rooms that had two different computer and color monitor stations. The subjects were asked to sit down in a chair that was positioned 15 feet away from the computer screen (Station 1) or five feet away (Station 2). Based upon pixel density difference between these two computer screens, the distance from the subject to the screen was different (either 15 or 5 feet) so that each pixel on the computer screen/monitor projected a solid angle of ~60 microradians at the distance of the subject's eye. Each subject had access to a keyboard and joystick connected to a computer, as well as typed instructions for running the Open-Door experiment in case they wished to refer to these instructions during the experiment. The subject's chins rested in a head rest to keep the distance from the computer screen constant. The Open-Door experiment consists of an opening on one of the four side of the box or, alternatively, no opening on any of the box sides. The subject was instructed to use the joystick to click the direction they believed the opening to be (up, down, left, or right). If the subject could not see an opening, the subject was instructed to guess or press the big red button that was on the joystick. The instructor described the Open-Door experiment to the subject and walked them through the trial run of the experiment. The colors of the foreground box (missing its Open-Door

gap) and different background color consisted either red (R), green (G), blue (B), yellow (Y), gray (A), white (W), or black (X). The pretests and experiments were designed to take no more than 50 mins so that the student subjects could complete the experiments within a standard hour class period. Each Open-Door trial took 2-3 mins and subjects were asked to complete each trial three times before moving on to the next color combination. Therefore, each subject was asked to complete one of eight different sets of 4-5 color combination series. For example, Set 3 consisted of the color combinations XoW, RoG, GoR, RoY, and YoR, where the first letter indicates the foreground (box with gap) color, and the third letter indicates the background color.

Some subjects completed the open door in the dark while others completed the experiment with the lights on so that an experimenter could examine the effects of general background luminance on the resulting visual acuities obtained. After the subjects had completed a series of trials, they were asked to fill out a post-test questionnaire to document experiences or difficulties that might have occurred during the experiment. The experiment was then concluded and the subjects thanked for their participation. Usually they were provided 10 pts extra credit (out of a total of about 1000 pts) towards their final course grades.

1.2.4 Experimental Design

The Open-Door experiment program was programmed by Mike Murphy and David McNulty of Sensory Cyber Systems LLC; Orono, Maine. This program allows student experimenters to change the foreground box and background colors easily without additional programming. The computer monitor or screen in Station 1 consisted of a LCD screen with a resolution of 1600x900 pixels. The computer monitor in Station 2 was an LED screen with a resolution of 3200x1800 pixels. In these experiments, we manipulated the size of the gap along with the colors that were being emitted from the screen. The automated process of the computer

program allows an acuity score to be obtained without manual calculations. The VISION automated program begins with a relatively large gap (Open Door) displayed on one of the sides of a box. Each time the subject correctly chooses which side the gap is on, the program will move to a second level of determination where it increases the gap size by one pixel until the correct side of the box displaying the gap is chosen. At this gap size, the VISION program continues to sequentially adjust the gap size until there are correct and incorrect guesses on either side of particular gap size. The acuity is determined by the arc width of a single pixel times the number of pixels in that particularly determined gap size. The VISON program records data leading to the individual's acuity score in terms of microradians (solid angle) subtended by the (Open-Door) pixels in that gap in the box emitted from the screen at the distance to the subject's eye.

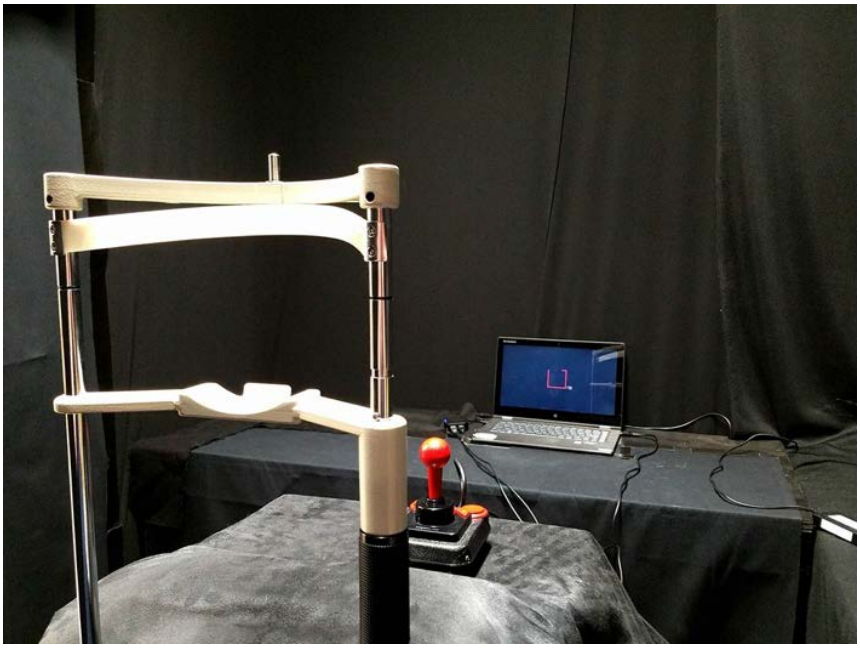


Figure 1.4: Experimental setup on Station 2 with (3200x1800) monitor.

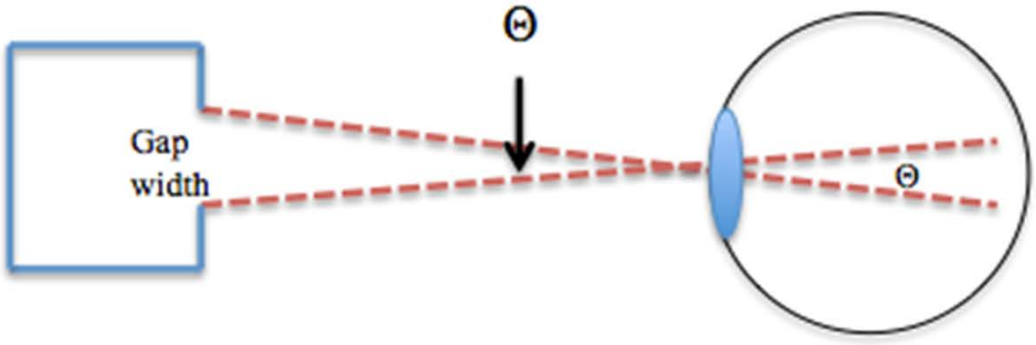


Figure 1.5: Representation of angle falling upon eye from the Open-Door Program.

1.2.5 Statistical Analysis

To assess if there were significant differences between two different color combinations, a One-way ANOVA was used at a 95% CI with GraphPad Prism and Excel. The figures were also created in both Excel and GraphPad Prism.

1.3. Results:

1.3.1 Comparison of Landolt C to XoW (Black on White) Open Door

The XoW (Black box on White background) was compared to the Landolt C visual acuity (VA) task through a comparison of individuals score in terms of minutes of arc. Each subject (N=26) completed the Open Door XoW three times (n=3). In each section of the results there will be N (biological replicates, each subject) and technical replicates which were completed by each subject (n=3). The subjects on average could discern a smaller gap with the Open Door XoW acuity task (0.646 ± 0.0389 minutes of arc) compared to the Landolt C (0.844 ± 0.0356 minutes of

arc). There was a statistically significant difference between the two forms of visual acuity examinations (p-value= 0.0005, 95 CI).

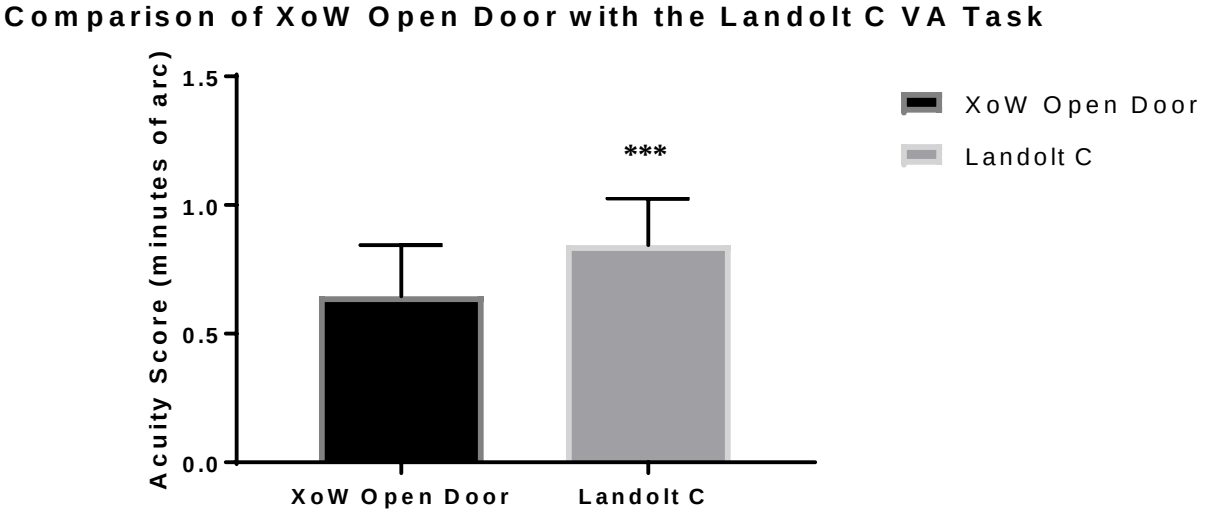


Figure 1.6: Comparison of XoW (black Open-Door box against a white background emitted from a computer screen) to the Landolt C room chart VA task

1.3.2 Effects of Color Combinations on Acuity Score

Through the VISION program we have been able to look at multiple color combinations in terms of background and foreground (box) color. The figures below represent the assorted color combinations that were tested on subjects. Figure 1.7 below shows a multitude of different color combinations and the changes in acuity that occurred with monitor 1 (LCD display 1600x900).

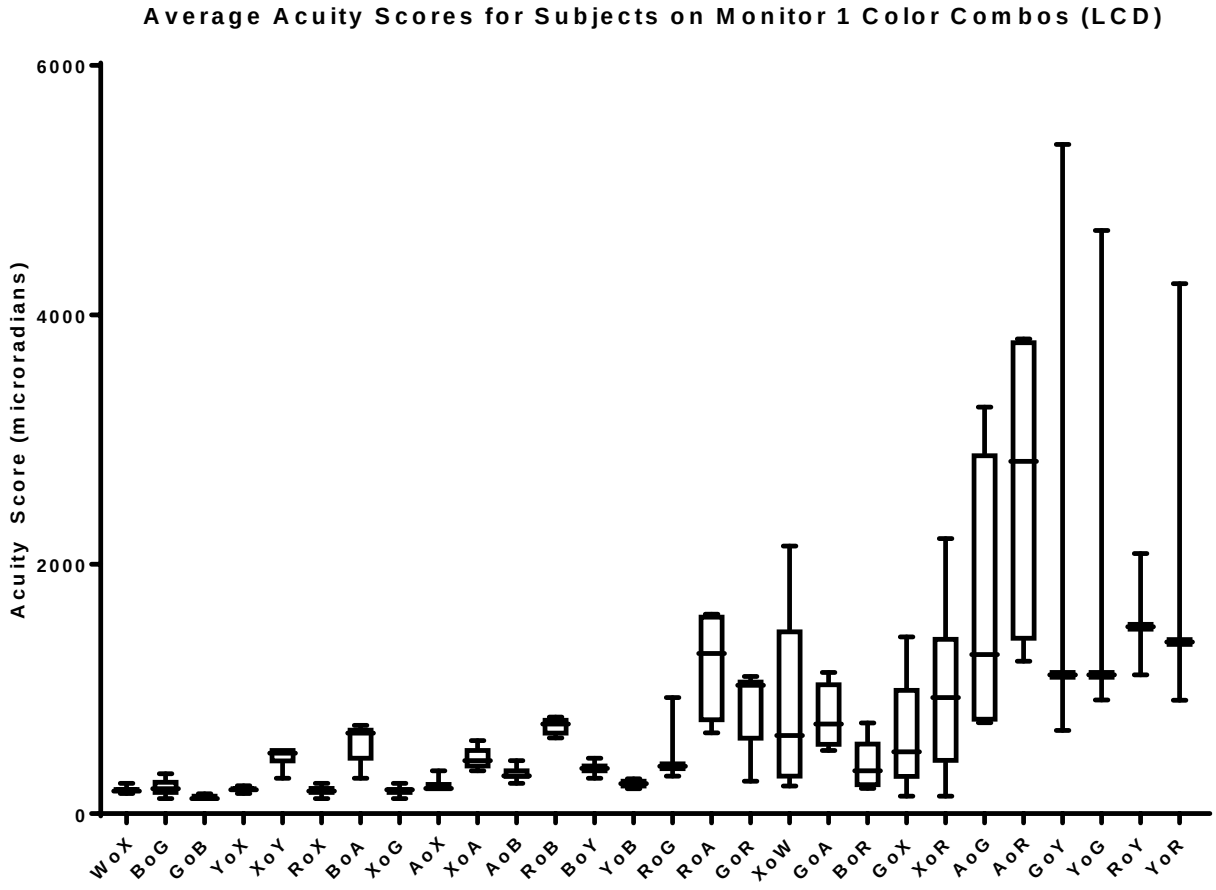


Figure 1.7: Experimental results of average Visual Acuity Scores obtained from 28 different color combinations on Station 1 (LCD) with female human subjects (N≥4 subjects each).

The color combination which provided the lowest average angle in terms of microradians was a green box on a blue background (GoB) with an average of 130±15.12 microradians. This color combination was followed by a red box on a black background (RoX) with an average angle of 181.8±42.11 microradians. Assessment of color combinations were also tested on the LED computer display (3200x1800), which led to varying results between the two computer displays.

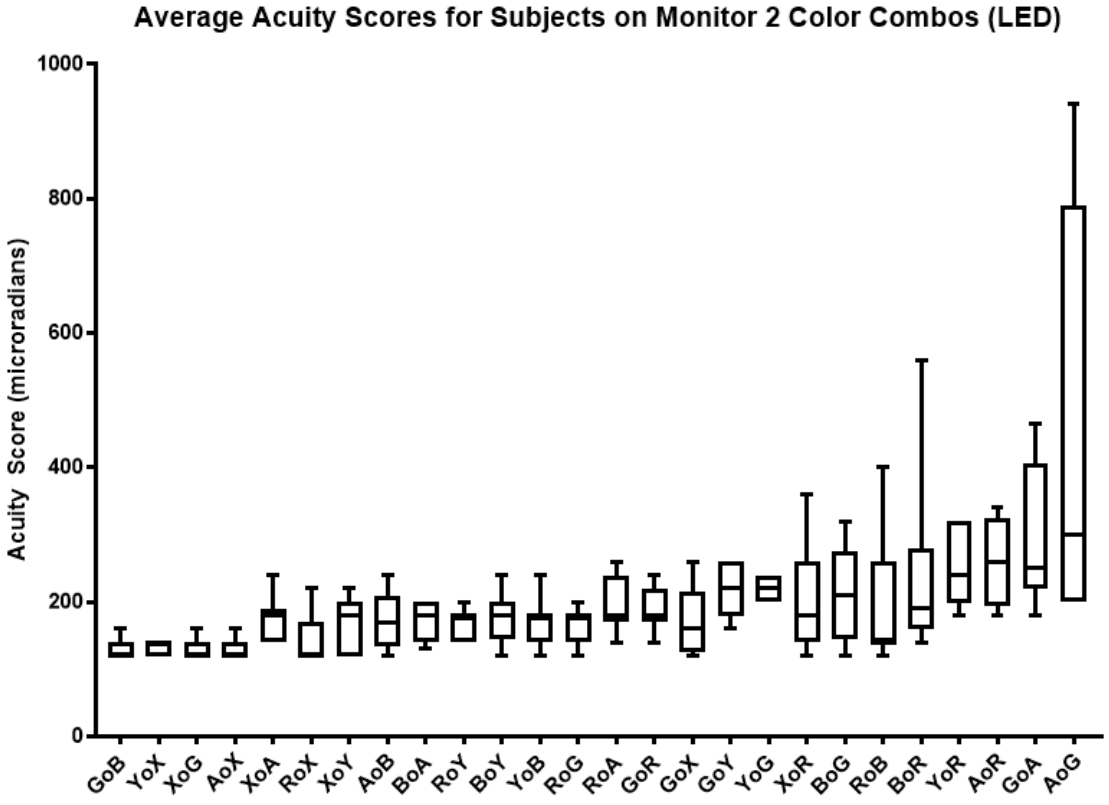


Figure 1.8: Representation of 26 color combinations on Station 2 with female subjects. (LED) (N≥6).

Comparing Station 2 (LED) with Station 1 (LCD) provided a range of different acuity scores with the variation in color combinations. Again, the GoB color combination provided a similar acuity score on both stations with an average score of 131.14 ± 15.74 microradians on Station 2. This color combination again was one of the lowest acuity scores for Station 2.

Previous work with the Open-Door VISION program has found certain color combinations to be harder for human subjects to distinguish [18]. Figure 1.9 a and b show the differences between the BoX (blue on black) and XoB color combinations. Station 1 (LCD) BoX had an average score of 902.2 microradians (15.04 pixels), while BoX had an average of 5373 microradians (89.55 pixels). A One-way ANOVA was run and a p-value of 0.0008 was achieved. The difference between these means was around 74.5 pixels.

Station 2 (LED) gave different results compared to Station 1. BoX had an average score of 168.3 microradians (2.805 pixels), while XoB had an average score of 293.3 microradians (4.83 pixels). Again, a One-way ANOVA was run and there was a significant difference between the two color combinations at 95% CI (p-value= 0.0106). The average difference in terms of pixels between the two color combinations was approximately 2 pixels.

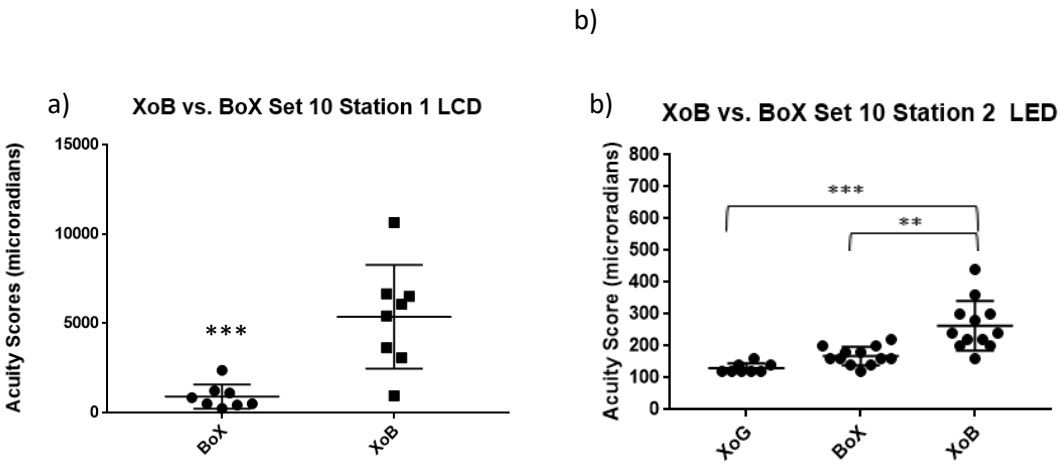


Figure 1.9: a) BoX and XoB comparison with Station 1. b) BoX, XoB, and XoG comparison with Station 2 (N≥8).

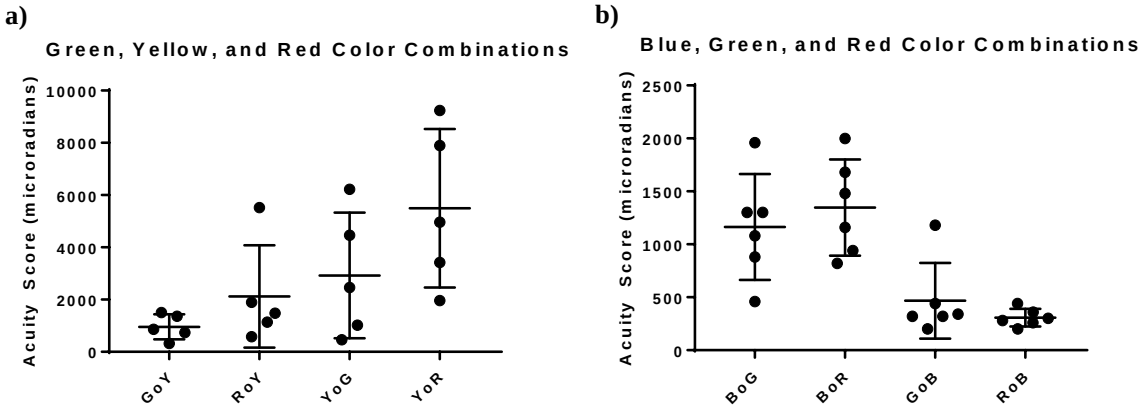
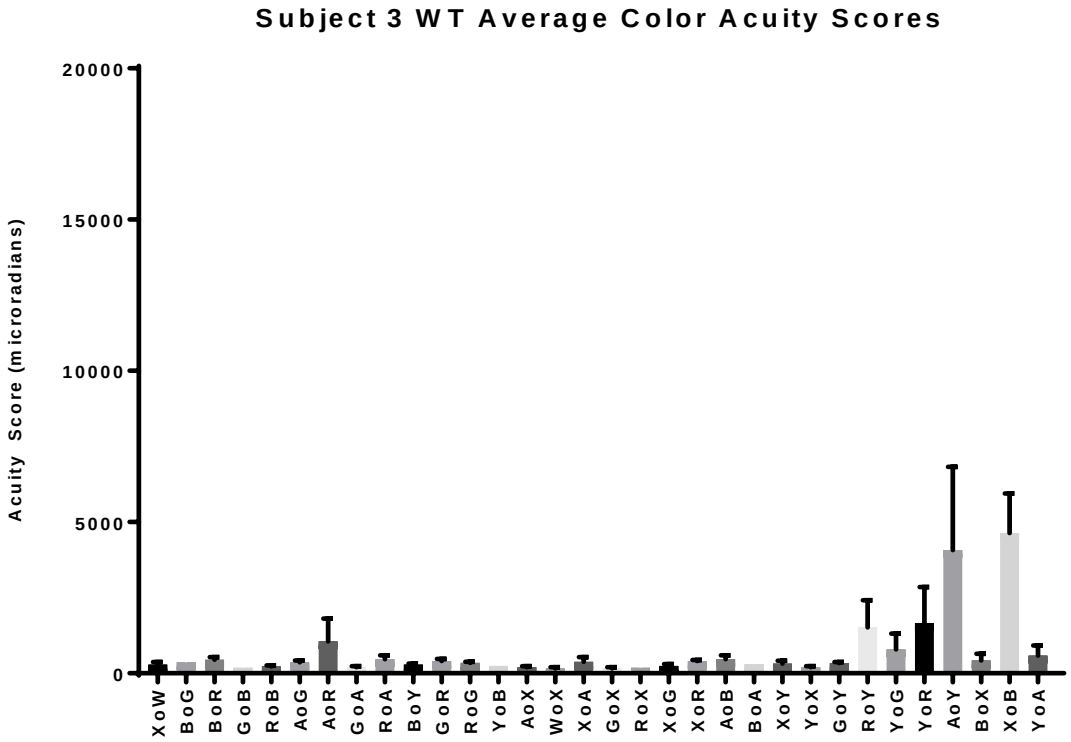


Figure 1.10: a) Comparison of green, yellow, and red color combinations with Monitor 1 (LCD) (N≥4). b) Comparison of blue, red, and green color combinations with Monitor 1 (N=6)

1.3.3 Color Deficient Subjects compared to trichromatic subjects

Color deficient (CD) individuals were recruited to participate in all 32 color combinations to obtain a full profile of their ability to discern assorted colors in an acuity task. A Wild-type (WT), trichromatic individual was also recruited to participate in this study by aiding in information into "regular" color discrimination in terms of acuity. These subjects completed each color combination three times and an average score for each was calculated. Figure 1.11 shows the individual profiles for both WT and CD individuals. Variations were seen between the trichromatic female individuals and the dichromatic male subjects.



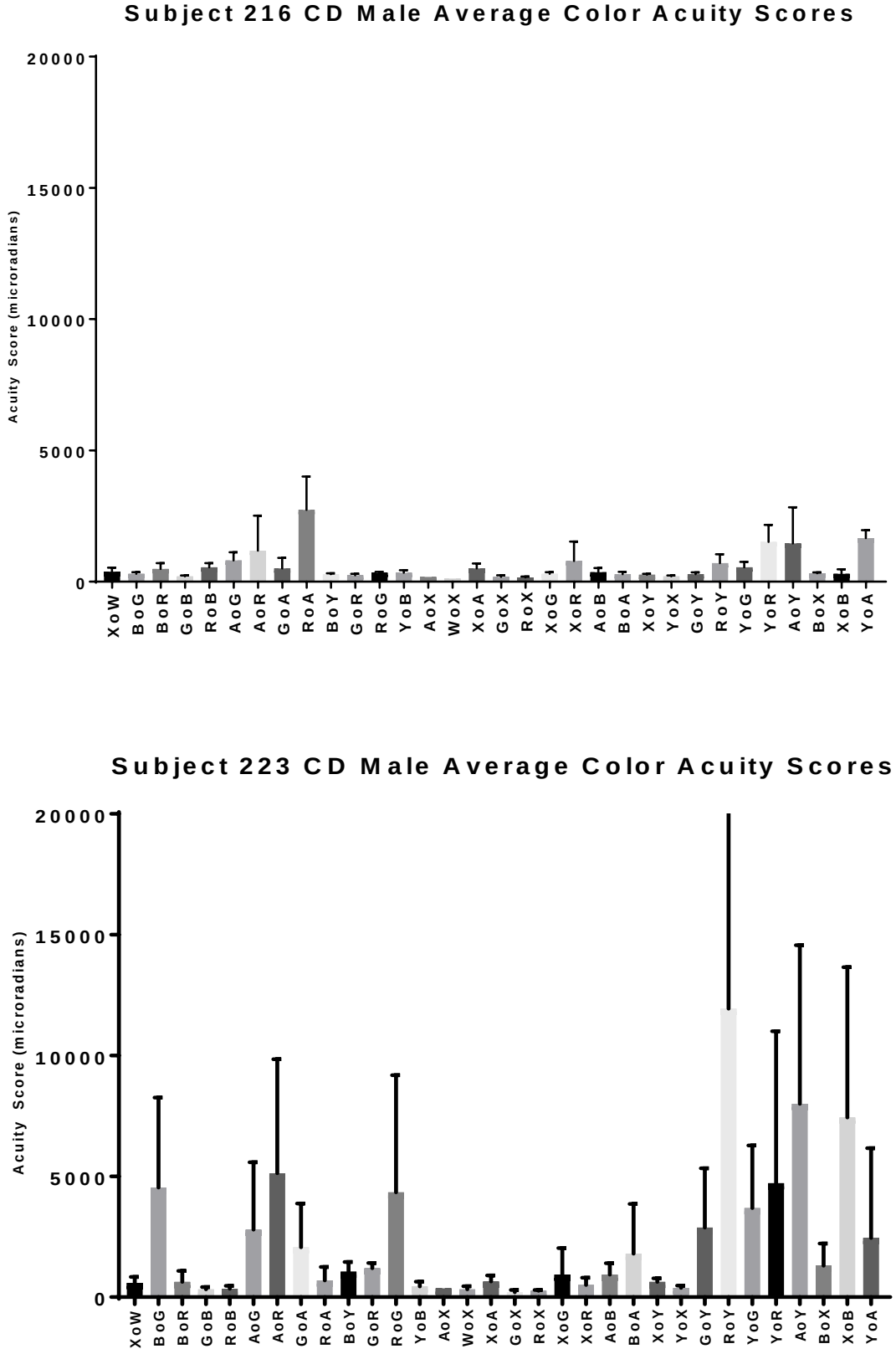


Figure 1.11: Individual profiles for WT (normal Wildtype female; top graph) and CD (Color Deficit males; bottom two graphs) for all 32 color combinations in the Open-Door experiments.

1.4. Discussion

1.4.1 Clinical Applications for the Black on White Open-Door VISION Program.

Visual acuity assessments are some of the most commonly conducted tests within the medical field. However, current methods for obtaining VAs are far from ideal because: (1) they are expensive to obtain because they require highly trained professionals to administer or interpret; (2) VA charts can be difficult to use outside of highly controlled clinical settings; (3) are limited to high contrast black and white images, most notably letters; (4) are not universal in that they require the ability to read in a particular language. The Open-Door program could be a viable and inexpensive route for assessing visual acuity with high contrast XoW (black on white) color combination. VA assessments using the Landolt C Chart, wherein subjects respond k as to which side of the circle has a break eliminates problem (4) above, but not problems 1-3. The Open Door program is an attempt to eliminate all 4 problems above. Since modern computer screens are comprised of pixelated grids, the VISION program utilizes a box in contrast to the Landolt C circle. Figure 1.7 shows that there is a significant difference between the two forms of analyzing individual's visual acuity. The XoW Open Door on average indicated the subjects score was line better compared to the Landolt C. Even though this was the case, the VISION program can be easily manipulated through default files, which allows quick change to box size and width. Therefore, further studies could investigate what the appropriate box size and width (or ambient illumination) would give exact values in terms of minutes of arc for both the Open Door and Landolt C. Recent advances in VDT (visual detection technology) has allowed computers, tablets, and smartphones to become means for easily and effectively assessing visual acuity throughout the world [17]. By making slight changes with the VISION program, there will be an effective

way to asses visual and color acuity that is functional for VDTs allowing for simple, easy, and mobile visual assessments.

1.4.2 Assessment of Color Combinations on Different Monitors

An objective of this study was to compare visual performance between the LCD and LED monitors. Results from this experiment show that visual performance was better on the LED screen compared to the LCD display. Figure 1.8 (LCD monitor) and 1.9 (LED monitor) allows for a comparison between the LCD and LED monitors. The LCD monitor on average had a much higher acuity value (in microradians) compared to the LED monitor. There could be several reasons for this to occur. One possibility for the varying acuity scores between the two monitors could be the differences in lighting conditions within the room. The LED and LCD monitors also may have different brightness in terms of emitted light. All subpixel colors (red, green, and blue) including yellow and gray were matched for intensity on the two screens. However, different types of monitors emit different spectrums of light for each of the three subpixel types. Therefore, when assessing how colors affect human visual acuity it is important to keep in mind the monitor used to generate and emit the colors as well as the spectrum that is produced by the monitor.

Even though there were spectral differences between the two color displays, resolution, luminance, and viewing angle are also important factors that may differ in varying situations. LCD and LED displays are continually advancing technology and with new displays like OLED (organic light emitting diode) will likely come advances to visual performance research [18].

1.4.3 Does assorted Color Combinations affect visual acuity scores?

A primary goal of this study was to examine the effects of different color combinations on human subject's visual acuity score. As previously noted, Figure 1.8 shows the average acuity

score for different color combinations (LCD monitor) for female subjects. There is a wide range of average acuity values for the color combinations. Most interestingly, the green, red, and yellow color combinations gave large average microradian scores with a broad range of variation. Yellow activates both L- and M- cones, while S- cones are not activated. L- and M- cones are both activated with these color combinations since the opponent color (red or green) is a part of the combination. Therefore, these color combinations could be harder to discern for human subjects due to the processes used by the retina and primary visual cortex to discern different colors. Another color combination that showed an interesting effect was the difference between black and blue. Previous work had identified BoX and XoB (blue and black) to be a fascinating color combination [19]. A black box on a blue background has proven to be difficult for human subjects to discern. This study has elucidated the XoB gap width at 5373 microradians, which is approximately 89.55 pixels. Therefore, subjects who must identify the gap width on the XoB color combination cannot determine that gap unless the side of the box is almost completely gone. The color combination with a green box and a blue background achieved the lowest acuity value on the LCD monitor.

Color contrast is important when it comes to assessing the hue of an object based on the background color. Therefore, due to the background color on the monitor, the box may be perceived as a different hue and may then be hard to determine. These results provide evidence that certain color combinations are better for the human eye to discern.

1.4.4 Do individuals perceive color differently?

There are a variety of different components that are important for perceiving and determining assorted color combinations. Color deficiencies usually arise when subjects have a

genetic mutation where they are missing their M-cones within the retina. However, from the data presented in Figure 1.11 there is not only variation between dichromatic individuals, but also differences between trichromatic subjects. These variances were also seen between the "wild-type" individuals and the average acuity score for all color combinations. As seen in Figure 3.5 there is large variation between the two color deficient male subjects. The two color deficient males went through a series of color assessments and were found that subject 216 had a strong red color deficit, while subject 223 had a strong green deficit. These differences in the male subject's color deficits may contribute to the drastic differences we see in their acuity scores in varying color combinations. Variations in genetic code and development can influence a myriad of factors that determine color perception. Some of these factors are the density of pigment found within the lens and macula, spectral peaks of cone photopigments, and the density of cone classes within the fovea [20]. These variations between individuals are known as color matching functions (CMFs). Each individual cone varies in terms of L-, M-, and S- cones within the fovea. Research previously mentioned that the male subjects' L/M cone ratios varied from 1.1:1 to 16.5:1 [6]. These varying cone mosaics may provide relevant information regarding why these different human individuals achieved varying acuity scores with the varying color combinations. Recent evidence has also pointed to mutations within the photopigments which changes the spectral peak sensitivity found within individuals [6]. However, these differences should be corrected by the color matching function within the brain. Therefore, there must be other differences further in the visual pathway that may explain these varying acuity scores based on different contrast ratios.

Recent research has investigated the response of peripheral retina in hue perception between monocular and binocular vision. Research has found that the temporal retina, meaning towards the lateral side of the eye, has more influence over binocular perception compared to the

nasal portion of the retina [21]. Even though these studies are investigating the peripheral retina, there are still some interesting research that may shed light on what is being experienced with some color combinations. Since the cone mosaics within the two retinas have different layouts, there can be a relative change in hue perception based on where the stimuli is landing on the fovea or retina. Further research could investigate the effect of monocular versus binocular color acuity scores based on the different cone mosaics within each eye.

Recent interest has involved the investigation of how retinal signals of color are perceived within the primary visual cortex. Evidence has pointed to the use of double-opponent cells to distinguish color boundaries within V1 of the primary visual cortex [22]. These opponent cells and receptive fields within the primary visual pathway are gaining momentum, however we still have much to understand regarding how the brain codes for hue and hue edge perception.

The VISION Program has demonstrated that with minor adjustments, it could be used as an additional VA examination throughout the world, due to it being universal and mobile. The program also demonstrated the large variation that occurs when multiple color combinations, with varying contrast affects ones' acuity score. Finally, individual results show a large variation between normal trichromatic females, which could be due to a variation within the retinal mosaic within the fovea, as well as higher cognitive processing within the visual cortex. Using VDTs for human vision research will provide more information on the basic properties of the human visual system and how it encodes information.

CHAPTER 2: TOWARDS ASSESSING CAPSTONE SCIENCE PROJECTS IN SCHOOL AND COLLEGE CURRICULA.

2.1 Introduction:

All degree programs at the University of Maine require undergraduate students to take and successfully complete a "Capstone experience" course for a minimum of three credit hours. However, the written description of what a Capstone experience entails are broad and vague. Due to this current ambiguity within the definition of the Capstone course, it can be difficult to assess if objectives or intended educational goals have been accomplished. Since the Capstone course has become an essential feature of every degree program at the University of Maine, a considerable effort at defining key features of all Capstone courses should be investigated and pursued.

The past decade has brought a large amount of attention to the importance of undergraduate research for professional development and student learning. Research conducted by Dr. David Lopatto has been at the forefront for the finding ways to quantify ways in which students gain experience through independent research. A study in 2004 piloted a survey called the Survey for Undergraduate Research Experience (SURE) to assess the gains that undergraduates were achieving while conducting research [23]. This work showed that students who conducted independent research projects had a better understanding of what they wanted to do for their career (i.e. postgraduate work). The survey also consisted of questions pertaining to gains that the students experienced after the research was completed. From the 20 questions on a scale from 1 to 5 (1- no gain and 5- very large gain), on average students experiences a gain of 3.72 with the highest score being "Understanding of the research process" 4.13 [23]. This study created a way to quantify how different research experiences affected undergraduate students.

The importance of independent research has been discussed in detail over the past two decades. Research has provided evidence regarding the ability for independent research to gain confidence in the ability to conduct research [24]. Not only does independent research provide experience which leads to confidence in undergraduate students, but it also provides important opportunities to learn skills in certain fields of science that students would otherwise not be able to have (knowledge of a certain subject, laboratory techniques, communication skills in science, etc.) [25].

Not only do these undergraduate research experiences give confidence and experiences to the undergraduates, it also helps with gender and diversity issues that have been seen throughout the science, mathematics, and technological fields. Research conducted at Tennessee State University (TSU) has discussed the impact that undergraduate research had on 12 males and 10 females of multiply ethnicities to further their career in the Geosciences [26] Therefore, beyond a graduation requirement, undergraduate research experiences present opportunities to socialize to the research realm and to become educated in the ways of authentic scientific research.

Structured research experiences, like that of Capstones, have been found to have many beneficial aspects. The Capstone is a culmination of a variety of skills and knowledge gained by the students during their undergraduate career. Many studies have investigated what important aspects the students gained from Capstone research experience. One aspect that students found important was the ability to work in a collaborative environment and obtain these interpersonal skills [26]. The Capstone experience also provides students with many of the similar benefits seen within independent research projects. The research discussed regarding the beneficial aspects of Capstones and independent research projects have provided the importance for providing this to undergraduate students at the collegiate level.

The second part of this thesis will discuss the creation of a set of guidelines within which Capstone courses in science can be functionally understood and eventually assessed to determine their effectiveness. Another goal of this section is to apply these newly established guidelines towards assessing the VISION project utilized in the first part of the thesis. The VISION project will also fit within these new guidelines. Finally, student surveys and interviews were analyzed in accordance with how well and in what ways the VISION project fulfilled its intended mission as a Capstone experience in science.

As currently stated, a "Capstone Experience" is required of every degree program at UMaine. The student Handbook states that;

"Every program must include an approved capstone experience. The goal is to draw together the various thread of the undergraduate program that bear directly upon the academic major in an experience that typifies the work of professionals within the discipline. Normally, the Capstone would conclude at the end of the student's senior year. Students should consult closely with their academic advisor to explore the range of options available for meeting this requirement." In the School of Biology and Ecology (SBE), the Capstone Experience graduation experience is currently fulfilled by taking once course (minimum of 3 credits) from a current list of eight possible courses listed here. (https://sbe.umaine.edu/undergraduate-2/biology/biology-requirements/requirement-for-bs-in-biology/).

These SBE Capstone Experience courses require a final paper that can be taken as a WI (Writing Intensive), but does not have too. A specific area of Bio388 (usually listed as "Capstone Research in Vision") and HON 499, are the two courses that are used in conducting studies within the framework of the VISION project.

It is imperative to note that, other than the general Student Handbook description of the Capstone Experience provided above, what SBE hopes their students to achieve from these courses and experiences has not been expressed has a whole. One goal in this thesis is to begin this conversation by providing a structured set of guidelines.

The set of guidelines that have been constructed here is for categorization of capstone experiences limited to the sciences (Biology, Ecology, Zoology, and Botany), but not necessarily to other STEM fields like engineering, technology, and mathematics. These set of guidelines may also not work for the categorization of capstone experiences in the other disciplines and degree programs, even though they may overlap in several components for Capstone coursework.

It is assumed that all capstones in SBE involve science exploration, but they differ in the relative degree to which they involve one or more pathways through which such science explorations may be pursued. For the sciences, and more specifically for the SBE, this section proposes that capstone experiences and their related coursework consist of one or more of the following four components: (1) Process; (2) Methods; (3) Background; and (4) Synthesis.

(1) Process

An example of a Capstone course in the sciences that would involve primarily (1), the Process component, would be a course with which the undergraduate would conceptualize experimental questions or hypotheses, design a detailed experiment to test that hypothesis, devise the means of collecting observations/ data from the experiment. The culmination of this would end with the analysis of the results and interpreting the results with regards to the original hypothesis proposed. Later, I will support the argument that the VISION project is an example of a Capstone experience in the sciences that does emphasize the Process component.

(2) Methods

Many laboratory and field-related courses in SBE provide important experience regarding the Methods component. A portion of the experience is learning and acquiring techniques and specific methods for conducting various experiments. Capstone experience and related courses involving the learning of substantial amounts of field and laboratory technique and methodologies would primarily fall under this component. For a specific example, learning how to record intracellular voltages from a neuron using electrophysiological methods involve a considerable degree of the methods component.

(3) Background

Some Capstones involve a "library research" focus which would mostly consist of this category (3). Working on this third type of Capstone project could involve reading primary articles and textbooks on a topic, for example, of Duchene's Muscular Dystrophy. Note that most standard lecture courses taught at universities and colleges provide "background" for the other Capstone components, including this one.

(4) Synthesis

The final components of a Capstone experience and related coursework is (4) Synthesis. A science capstone course involving a vast degree of synthesis would entail combining information from multiple sources and integrating their ideas in an innovative and creative way. An example of this would be if an investigator were to read extensively about a certain disease, and combine this information with new evidence to create novel ideas or hypotheses on the phenomenon that is occurring. This form of activity would involve a considerable amount of synthesis.

It must be emphasized that most Capstone courses in the SBE have and should have varying amounts of exposure to all four of the components discussed above. By breaking down a capstone into these components, it allows for better ways to assess the success of a specific Capstone project. If a Capstone project focuses primarily on one component, and only a small portion on a second component, then it should be weighted differently while assessing and evaluating these different components of a Capstone project. It is assumed that without a clear understanding of what components these projects are attempting to emphasize, then any assessment would be rendered most difficult, if not impossible.

Capstone projects in SBE requires that the undergraduate submit a paper to the instructor who is responsible for assigning a course grade and credit. A traditional science research paper consists of certain sections such as background, methods, results, discussion, and references. These sections of a traditional paper correspond closely to the four components of a capstone project discussed early in this section. This large correspondence between the Capstone experience in the sciences and the traditional research paper is the principal reason, although before this has never been made explicit, why a research paper is a requirement for completing a capstone in SBE. An emphasis should show that a large component that may be missing within the traditional research paper is the (1) Process component. The VISION project was the example given above having the process component as its major attribute, which will be address next.

2.1.1 Development of the VISION Project Research Capstone with its Process Oriented Education Component

The VISION Project, as it is referred to today, has evolved throughout the years, since its first inception in 2006 within the laboratory of Dr. Len Kass in SBE at UMaine. This evolution has provided many undergraduate and high schools students the opportunity to use technology to assess question on the human visual system. These projects come from various capstone research, Honors Theses, and Upward Bound Math and Science Summer Program (UBMS) for high school students. During the 2016-2017 Academic year, 16 undergraduates at the University of Maine have participated in the VISION project as part of their Capstone projects. This minimal-cost, process-oriented, universally-designed project, as applied towards science education, is capable of expansion beyond the laboratories of the University of Maine to include student experimenters in middle schools, high schools, and college nationally and internationally. The newly programmed and designed automated Acuity Program may someday be adopted to serve health needs in rural or impoverished communities.

2.2 Methods:

Five of the students from Bio388 completed the CURE survey once they had completed their VISION projects at the end of the fall semester. The CURE survey was completed by following the link to the CURE website (https://www.grinnell.edu/academics/areas/psychology/assessments/cure-survey), which contained specific instructions for the faculty and students. Once the students had completed the post course survey Leslie Jaworski and Dr. David Lopatto analyzed the data which was sent as a report. The full 10-page CURE report provided by Grinnell College on the results summarized here is attached to this thesis as Appendix G. The responses from our five Bio388 Maine students are compared with over 4000 undergraduate students (labelled “All Students” in figures) from other institutions who have taken the CURE survey. The comparisons are with respect to their demographics and classifications (Appendix G, pages 2-4), the course elements

and gains (Appendix G, pages 5-6), benefits and learning gains (Appendix G, pages 7-8), and attributes about science (Appendix G, pages 9-10). The four students who volunteered for these one-on-one interviews were paid $20 to participate and were guaranteed confidentiality and verbal accepted to complete the interview. The interview was conducted with a semi-structured technique that had pre-determined questions, however were open ended to encourage discussion. This form of interview allowed for particular themes to be explored. The pre-determine questions that were asked by the interviewer can be found in the appendices (Appendix H). The interviewees were given ID numbers; therefore, no names were associated with the participant. Finally, the audio files were run through VoiceBase to convert them to text files.

2.3 Results:

The goals stated previously about the VISION project are ambitious. How well does the VISION project function as a science Capstone in the SBE program at Maine? The first section within the results will provide information analysis from the CURE survey. In addition, four of the five Bio388 students agreed to volunteer ($20 compensation for their time) to be interviewed at around the same time as the CURE survey. Their comments and analysis of these responses to the interview questions will be provide in section two of the results section.

2.3.1 Results from the preliminary comments on the undergraduate CURE survey after VISION Project participation in a Bio388 Capstone course.

The results reported here will focus on certain items within these course elements gains, learning gains, and science attitude responses from the Bio388 Maine students compared to the others that are germane to the present discussions on general learning outcomes from science Capstone experience and the specific characteristics of the VISION

project as a capstone experience at Maine. The emphasis will be on the differences (more or less) in values between the University of Maine undergraduate students, and those students in other related coursework at other college and universities.

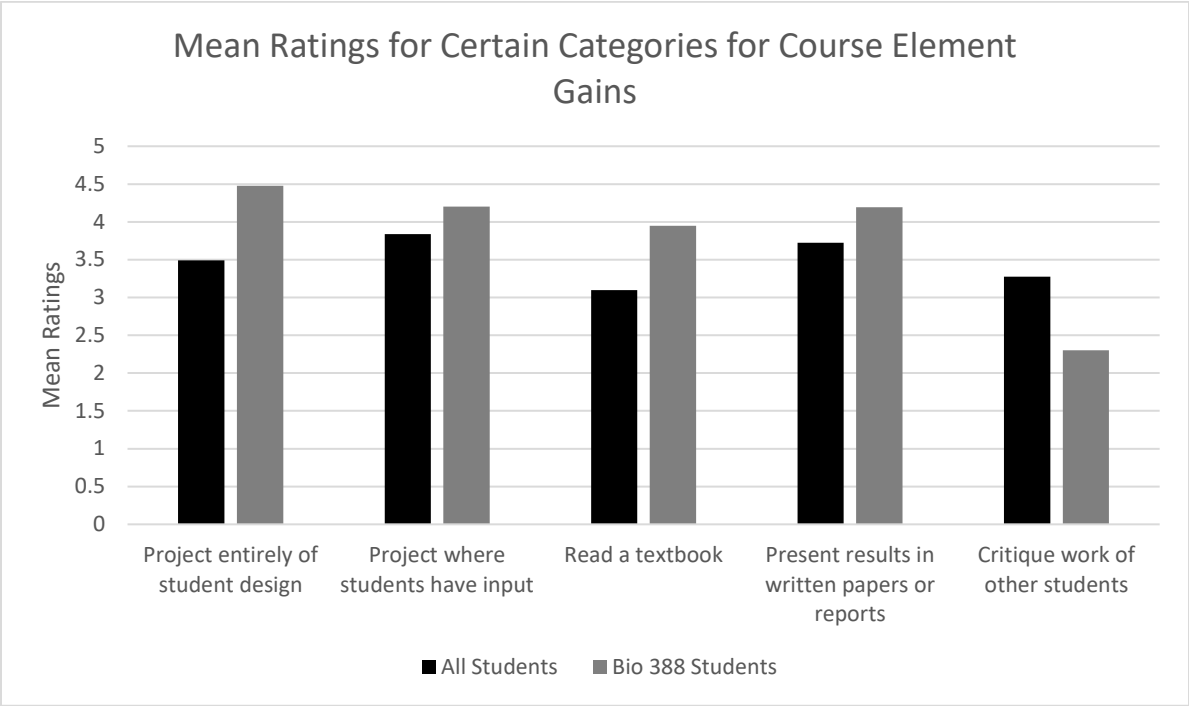


Figure 2.1: Data extracted from page 6 of the CURE report based on the Post-Bio388 Capstone course near the end of the fall semester 2015 student responses.

Figure 2.1 lists all the 25 items of the CURE survey report that relate to "Course Elements Gains.". The survey choices were from 1 (lowest) to 5 (highest). The higher the score of the average opinion of the students of that element indicates its importance to the student and that the item was emphasized in that course experience. Note that the five Maine students indicated that the VISION project upon which this Bio388 Capstone is based ranked especially high in the "Projects where students have input," "Project Entirely of Student Design," "Present Reports in written Papers or Reports," and "Read a textbook" items. The students scored the item "Critique work of other students' far below the average of other students at other institutions who have gained Capstone-like experiences other than from the Maine Vision Project.

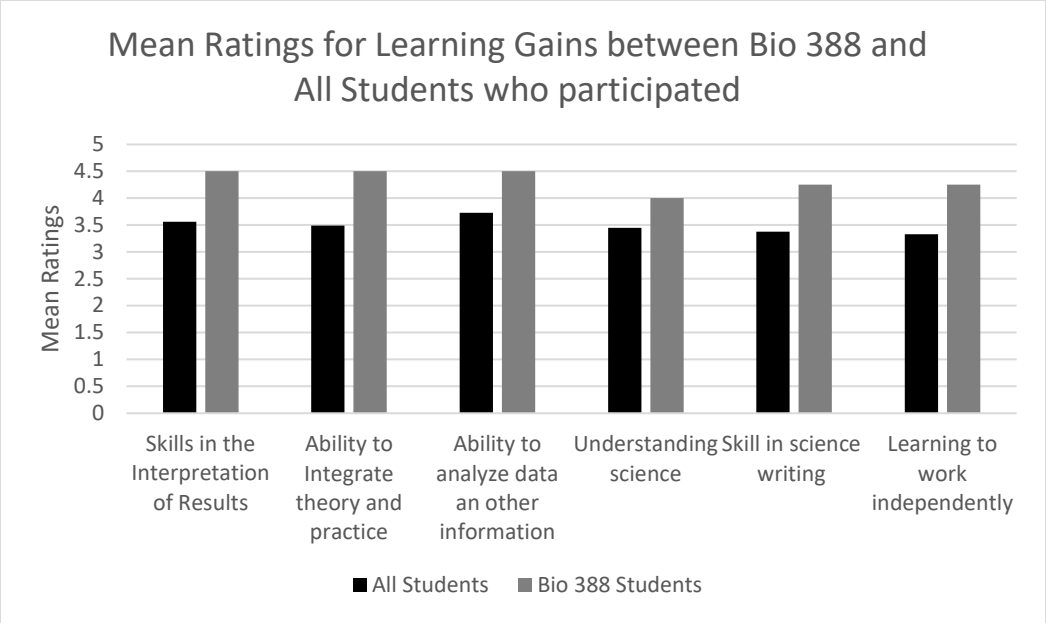


Figure 2.2: Data extracted from page 8 of the CURE report based on the Post-Bio388 Capstone course near the end of the fall semester 2015 student responses.

Figure 2.2 lists all 21 items of the CURE survey report that related to "Learning Gains." The survey choices were from 1 (lowest) to 5 (highest). The higher the score of the average opinion of the students of that element indicates its importance to the student and that the item was emphasized in that course experience. These findings indicated that the VISION project which this Bio388 Capstone is based ranked comparatively high in the "Skill in the Interpretation of results," "Ability to Integrate theory and practice," "Ability to analyze data and other information," "Understanding science," "Skill in science writing," and "Learning to work independently."

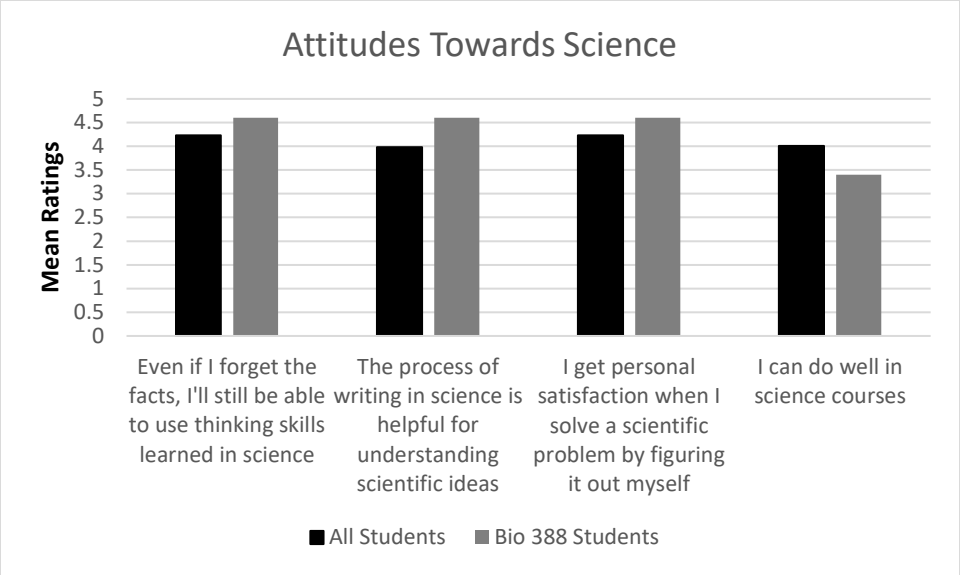


Figure 2.3: Figure shows four of the questions asked during the Attitudes about Science extracted from page 9 of the CURE Report.

Figure 2.3 lists 14 items that are related to attributes about science. As previously stated, a score of 1 indicates that students strongly disagree, whereas a score of 5 indicates a strong agreement with the statements. Students from the Bio388 course indicated that the VISION project ranked especially high in (italicized and blue) the "Even if I forget the fact, I'll still be able to use thinking skills learned in science," (x=4.60) "The process of writing in science is helpful for understanding scientific ideas," (x=4.60) and "I get personal satisfaction when I solve a scientific problem by figuring it out myself." (x=4.60) Bio388 students at Maine engaged in the VISION project had lower scores for the "I can do well in science courses." (x=3.40) As discussed in the official CURE description of the 4 highlighted items, those four correlated strongly with what they term "engagement." This would mean that those participating five Bio388 Maine students engaged in the VISION project scored high in 3 of the 4 "engagement" items, but lower in 1 of those 4 items.

2.3.2 Results from preliminary comments on the direct interviews of students after VISION project participation.

Interviews were conducted on four of the five students as they were finishing their Bio388 VISION Capstone course at Maine. The entire transcripts of these interviews are attached to this thesis as Appendix G. This section extracts, abbreviates, collates, compares, and summarizes the responses to the same or related questions. The questions asked were similar from student to student, but not precisely worded as such. The responses were consolidated from different students to the similar or related questions resulting in four basic questions: (a) What did you like most? (b) What did you learn? (c) What more would you like to learn? (d) What improvements would you like to see made? The #'s indicated which student responded to the question which can be seen in Appendix G.

A. What were your favorite aspects of [your Bio388 Capstone VISION Project?]

One of the more common themes that arose while the Capstone students discussed their favorite aspects of the VISION Project was about the independence that they saw with the VISION Project. Many of the interviewees brought up this aspect during their interviews by saying:

> #1: "My favorite part was that it was pretty independent. I didn't feel like it was a normal science class in which you were being guided. Because that is how I feel are like a lot of science classes are right now. For example, in Biochem Lab it's slow-paced and it feels like freshman year over again. But, like I said, it was nice that it was independent and I felt like I was in charge. We had the opportunity to do it ourselves, but I didn't take the opportunity to be a subject myself."

> #2: "It was very open, you didn't have to actually come in and do it. I work in Aubert and you have to be there to do it. I liked how you can bring this home and work on it instead of being in the lab at all times."

> #3: "I find it is definitely different in the lab and undergraduate labs are pretty much done for you. I make sure subjects did the experiments and I kind of set it up for them in terms of running the experiment."

> #4: “I did [like the fact that] I didn’t come in with any preconceived notions and just came in saying "Let’s see what happens". For the most part I did think it was different from undergraduate lab reports. I was new to the structure, but like organic chemistry when I got a wrong IR I know I did something wrong. However, this research is so open ended and you don’t know what is suppose to happen. I did like that and had freedom. You weren’t forced to think a certain way and hope something would happen.”

Four of the five students identified that the “independence” and “not knowing the outcome” as one of their favorite aspects of the project. The VISION program is a different area of research where the PI does not know the outcomes of the study, which is an attractive aspect of the project.

B. What did you learn or what skills did you acquire in this project and course?

Another aspect that is important for science research is the ability to learn skills in terms of methodological approaches and general knowledge about the system that is being studied. Many different skills were brought to light by the students, which provide insight into the key skills gained during the VISION Project work. Some of the interviewees stated:

> #1: “I didn't think I noticed until I sat down with Dr. Kass the other week and the way he explained it. I thought I have been doing this my entire college career and it is such an overwhelming course, but I totally developed these skills. Especially this semester.”
>
> “I think that there is one concept that I learned was that the lack of someone’s experience with the experiment can get in the way. Like I felt like I am doing something wrong and therefore I am distracted. Learning how to work with humans I think is important for research. I do think that the data is more of my own since I collected the data and analyzed the data I collected and constructed the questions around it.”
>
> “First off I didn't know how to run a Landolt C test. I would say I learned a lot about talking to people in a research and professional setting. I also learned that research is a team effort and collaboration is a beautiful thing. I learned how to work with other students in a professional setting as well.”
>
> #4: “I did learn about how to run experiments and about the visual system.”
>
> “I mean I have been using excel a lot for many lab reports so I think I knew a lot, but the analysis part I learned a lot about how to do the manual and it made me

> appreciate the automated program. I learned more about the formulas and not just putting the data into the sheet."
>
> "What I thought was good was being able to apply skills and things I learned from the past about controls, subjects, etc. was really good for this, but mostly applying old techniques."

Many of the components that were brought up by the students were important in the process of the VISION Project. One key important skill that the students gained was the ability to interact with human subjects, which is important if the students were interested in working within the medical field. Another skill that students seemed to bring up was the ability to use Excel to convert data in ways to analyze and interpret what these visual acuity scores were showing us in a broader context.

C. Is there anything in terms of techniques or skills that you would like to improve upon?

Techniques and other methodological skills are important for various capstone projects. However, the VISION Project has been known not to contain various methodological approaches or bench work techniques. Many interviewees did not have much to say about this question, however most of their answers were in regard to interacting human subjects;

> #1: "Well what this has helped me practice was with my other job. I just got trained in home care and it always starts with a survey which ours did as well. Working with things like confidentiality and stuff like that is part of my job so that is a part of my job that this helped with. So, what I need practice with is my time management for sure. Actually, running the experiments has given me some good experience, like I am more comfortable talking to strangers. I think I probably need practice on being personable and professional because it is a balance and you can be off putting being a certain way."

Another undergraduate within the program expressed a skill that does not just pertain to doing research within a lab, but an overall life skill that is important:

#2: “Time management.”

D. What parts or aspects of this Capstone course do you think we could improve upon?

Finally, one of the most important questions revolved around what the students believed would make the VISION Project as a Capstone more effective. There was a common theme where students mentioned the ability to see other VISION Capstone papers would helped them with their own writing:

> #1: “I think what would have really helped would being able to look at papers and looking at similar papers to give us more structure. But again, after I sat down with Kass, I was like wow I know how to do this.”
>
> “Possibly giving out old capstones so students could get an idea of what happened previously. I think that would be good when we are forming are hypothesis so we are not overall. I do think it is reassuring that if you don't find anything that it is okay however.”
>
> “I think that I wish I had come in earlier and talked to the professors to get my paper in earlier. I was supposed to have it in in April, so maybe going in for a week or two to get help and reassurance about the work. So maybe just encouraging people to come in when they need help is a clever idea. It just took a simply conversation and look at the data to give an idea where to go with the paper. Even just letting us know that you are up here to help as well just in case we can't meet with Dr. Kass. The communication was really good in terms of who was supposed to be running the experiments and what stations were running.”
>
> #2: “I like how DK sat with me and helped with the data and the sheets of paper with the steps to analyze the data. There was some data that was messed up and I fixed it which made me feel good and updated the papers. It was nice because you didn't have to know exactly how to use excel before analyzing the data. I wish I knew more statistics, but that would be another course. Maybe teaching what types of statistics to use. (Yes). I didn't use any stats on my capstone. So, I think that would be helpful with [concepts] like correlation.”
>
> #3“How to conduct independent research. Maybe it would help to have all the previous research papers to look at what they did and make connections between the data.”
>
> I’m sure it’s frustrating because we aren’t sure if we are wrong. So, I think that’s the thing that could be frustrating because you want to be contributing to the research.

> "Not necessarily a suggestion, but at my old school when I was a freshman we were required to write for our lab reports, they had to be at least 12 pages, but it didn't have as much instruction. Like in organic chemistry it is different because we didn't have an abstract for our lab write ups. Maybe if there is a bit more structure about what is expected in the paper in terms of structure (sections)."

Some of the students also pointed out that having lectures or meetings on the visual system and prior experiments could provide them with background information;

> #1: "I feel like we should have some more meetings during the semester. Maybe a meeting at the end of the semester."
>
> #2: "I wish I knew more statistics, but that would be another course. Maybe teaching what types of statistics to use. (Yes). I didn't use any stats on my capstone. So, I think that would be helpful with [concepts] like correlation."
>
> #3"I kind of wish that Dr. Kass had more meetings with experiment setup and data processing, so I wish that he had more meetings with the group. Maybe having a time associated with the class on MaineStreet where you can come in, but don't have to. I feel like I have to physically be there and that will help me get things done and understand them more, instead of just dong an independent study. I need to practice time management."
>
> #4: "I know we had a couple of meetings with Dr. Kass more so about what was expected and how to run the experiments, but there wasn't much about what he was hoping to get out of the experiments. A couple more lectures even just about what is previously known about this previous research. What knowledge is already known about the topic and vision research has been done. When I was doing my Capstone, I did find research on and coming in with some information would be helpful before working on the Capstone paper."

Finally, there were some aspects of the project where the students expressed interest in changes to the experimental procedure for the VISION program:

> #2:" I think it make the person be the subject because he doesn't have us do it sometimes and then it is hard to explain exactly what to do for the subjects. I wanted to do all the color combinations and look at the complimentary colors, but ran out of time."
>
> "Maybe just have one station. It was busy in the lab. It was interesting how the lab is setup."

#3: “I feel like it is a lot of things to complete in one semester. Maybe collect the data the semester before and then focus on the paper the whole semester, but I think it was a good amount of time between data processing and creating the paper. I also wish I could have been a part of the IRB process, because I feel like in the future if any students wanted to do a capstone in the future they don’t really know anything about the IRB process because he always does it.”

#4: “I thought everything was pretty good!”

“What I didn’t like was that Dr. Kass has been doing this research, but I think it would have been nice to let the students have a little more input into how the experiments were run. There were a couple things that I noticed when going through the experiments myself that I didn’t necessarily like. The main thing was the length, which I understand but there were a couple times when I was seeing the boxes, but I would hesitate and choose something fast because of the 3 second time limit. It was more so guessing and if I had a few more seconds and let my eyes focus I would have probably gotten a better value. The box itself doesn’t have thick lines, so adjusting the thickness.”

Receiving information regarding ways in which we can improve the VISION Capstone experience was valuable information to gain from these undergraduate students who took the time running the experiments with the subjects.

2.4 Discussion

2.4.1 Analysis of Student Outcomes from the VISION Project Surveys and Interviews

Even though there was a small sample size; comparing their responses to the online CURE survey and from the interviews, there was a very close correspondence between their Course Element Gains (Figure 2.1) and the student interview questions (a) “What they liked most about the VISION Project”. Namely, that the students ranked relatively high aspects such as “Projects where students have input”, “Project Entirely of Student Design”, “Present Reports in written Papers or Reports”, and “Students Work Independently”. These students rated the VISION project lower in “Present results Orally”, “Present Posters”, “Critique Work of Other Students”, “Take Tests in Class”, “Present Posters”, “Maintain

Lab Notebooks", and "Computer Modelling." Some of these components like that of "Project Entirely of Student Design" seemed to be important aspect for undergraduate research [24]. The responses obtained from the interviews on question (a) highlighted the independence the students felt they had, and appreciated the "hands on" nature of the research.

In evaluating their responses to the 21 Learning Gains elements (Figure 2.2) and comparing these to the students interview question (b) "What did you learn or what skills did you acquire in this project and course?", there were positive correlations between these as well. The students participating in the VISION project scored rated higher scores on average ALL 21, except 4 of these elements: "Understanding Scientific Assertions….", "Learning Laboratory Techniques", "Skill in How to Give an Effective Oral Presentation", and "Confidence in my Potential as a Scientist". The student's responses to the interview question (b) indicated that they felt they had learned a lot while applying knowledge to some practical problems in human color vision. One student stated that "…. I thought I have been doing this my entire college career and it is such an overwhelming course, but I totally developed these skills, especially this semester." It was surprising to see how the VISION Project results compared with the responses from the 2015 SURE (Summer Undergraduate Research Experience) program responses. The SURE program is a summer research program wherein students are selected to participate in funded laboratories of research scientist. The students involved in the Maine VISION project cored higher responses in 19 of the 21 Learning Gains Elements (Figure 2.2), the two exceptions being "Learning Laboratory Techniques", ad "Skill in How to Give an Effective Oral Presentation". This has also been seen to be an important aspect of undergraduate research

throughout the nation [25]. As previously mentioned, Maine VISION project scored high on 3 of the 4 “Engagement” items (Figure 2.3), again reinforcing student interview response from questions (a) and (b).

However, like all Capstone experiences, the VISION project has its limitations and weaknesses. Due to the design of the project there are some inherent limitations and some of these weaknesses may be how the project is conducted. These inherent limitations lie mostly in the fact that this project emphasizes the Process of scientific investigations, and much less on the other components previously discussed. Interview questions (c) and (d) highlight some of these inherent weaknesses in the VISION Project. When the students were asked about what ways we could improve the VISION Project or what skills they would like to see involved with the project, they had much to say. Their suggestions mostly obtained to the Background and Synthesis components. The students also listed limited learning of laboratory methods and techniques, however, these students may have self-selected the VISION project over other more standard laboratory oriented Capstone experiences and therefore did not miss that Method component.

2.4.2 New Guidelines for Future Assessments of Science Capstones

The Maine VISION Project can be compared to other science Capstones and assessed based on the qualities or components previously discussed above. It must be emphasized again that these general components fit within the Science area of STEM, and while technology, engineering, and math may have some of these components, they also differ in unique ways. Capstone experiences outside the science fields may have drastically different components compared to the sciences. These ideas which follow are more of a

theoretical approach to addressing questions associated with assessments of science Capstone experiences.

a. Four components of every science Capstone experience

As previously stated within the Introduction there are four theoretical components to a traditional science paper. These components are (1) Introduction and Background, (2) Methods, (3) Results, (4) Discussion. These components have been used for many years for numerous science publications. Perhaps, it is not surprising then that these components found in traditional science papers are key components found within a Capstone experience as well as the student's final research paper. Instructors require a full report and do not require on the (2) Methods, or the (3) Results section. However, different Capstone experiences emphasize the importance of certain components over others. I suggest that all Capstone experiences should contain one or more of these components of scientific study. Instead of listing them of Background, Methods, Results, and Discussion, listing them according to clearly defined assessable components. I propose that these components for assessing Capstone experiences in science be named: (1) Process, (2) Background, (3) Methods, and (4) Synthesis. In the Introduction in Part II I described examples of the latter three components, however, (1) Process is a bit unusual in that it does not fully correspond to a section of a thesis or paper. Even though it is not easily fitted within this set of guidelines, it is still a major component of the scientific investigation itself, which is the scientific process. Observing, creating a hypothesis, devising a way to test that question/hypothesis, conducting the experiment, collecting data from that experiment, analyzing the results,

discussing the findings as how they relate to the original hypothesis are all important factors that experimental scientists go through. Even though this process is innate in nature, it is not always shown through the finalized product, which is a paper. Therefore, I have added it here because it is possible to create and conduct a science Capstone whose primary goal is to help students maneuver through this fundamental process of science.

The VISION project is an example of a primarily process based Capstone experience. This is not to say that the VISION project only focuses on the (1) Process component, but rather has some degree of the other three (2-4) components. The VISION project does require a degree of background (2) readings in the areas of color and vision anatomy/ physiology. It also requires proficiency in methods (3) and trainings in confidentiality and interaction with human subjects, data analyses using data arrays, tables and graphs in Excel, statistical analyses, etc. Finally, the VISION project also requires a bit of synthesis (d) in a way of comprehending the results and comparing this to what is already known about the human visual system. Discussions (Synthesis component of paper) of some students involve undergraduates putting their results in context within a genetic, anatomical, physiological, ecological, and evolutionary standpoint. Therefore, different Capstones differ on the quantity and the quality of each component encompassed in their Capstone experience.

b. Assessing the Quantity and Quality of each component in a Capstone Experience.

Moving forward to properly assess a Capstone, the quantity of each of these four components should be approximated by the principal investigator (PI)/instructor.

Subsequent student or colleague evaluations could then be administered to evaluate whether the expected quantities were similar to the observed quantities.

To evaluate the quality of ones Capstone experience, surveys like the CURE used in this study, or some other future assessment tool could be used to assess this. As seen in Figure 2.1 and 2.2 the CURE survey provides meaningful information regarding certain aspects that the students thought were important. Dr. Kass (instructor of Bio388: VISION Project) indicated that he would estimate the Process: Background: Method: Synthesis as roughly half Process and the other half roughly equal in a ratio of 3:1:1:1. Some aspects of the CURE survey could be used to quantify the degree to which students observed achievement within these four components. As seen in the results the students who worked on the VISION project ranked highly certain elements like "Projects where students have input" and "Project Entirely of Student Design". These two elements most closely corresponded to the Process component. Looking at the student interview from question a. "What were your favorite aspects of [your Bio388 Capstone VISION Project]?", do support Dr. Kass' attempt to create a Process based Capstone experience. Certain elements like the Background and Method components are also not fully emphasized which are known and can be observed through the interviews and CURE assessment.

c. Towards a Novel Approach for Assessments in Science Capstone Experience Courses.

The Grinnell College CURE survey has some positive elements towards assessing diverse types of Capstone experiences. The CURE survey is a free service and the web site is easy to find along with being user friendly by a large number of undergraduates and faculty. As you can see from the different elements provided in the CURE survey,

there are a multitude of different question types. The CURE survey provides three different areas to assess the views of the students on the research experience. The three categories as seen in the results are Course Element Gains (Figure 2.1), Learning Gains (Figure 2.2), and Attitudes about Science (Figure 2.3), which are also combined with the Engagement indicators (Figure 2.3). Not only does the CURE survey provide information about the students within your course, but they also provide information about participant demographics and comparisons of your own students compared to the average of other students at different institutions who participated in the CURE survey as well as averages from the SURE survey.

However, like all assessment tools there are limitations. Putting aside the technical issues of not receiving the data in an Excel form and not being able to readily modify and consolidate certain components, there are still some conceptual issues. In this part, I have proposed an innovative approach to assess science Capstone experiences that could be used basically for Honors, Masters, and Doctorate theses in the natural sciences. My proposed form of assessment would divide the approach into four basic components that would constitute in varying degrees of the science papers and theses: (1) Process, (2) Background (3) Method, and (4) Synthesis. Therefore, any future assessments would have categories corresponding to those four critical and time-honored components. As stated by many students, there should also be a "Presentation" (either poster, oral, or both), while not a traditional component of any scientific research paper or thesis, it is an important aspect to be able to successfully articulate your research. This is a defining characteristic that allows scientist to be successful. In

conclusion, Part II has attempted to provide a novel set of guidelines upon which assessments of vital components of a science Capstone experience can be based.

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APPENDICES

Appendix A: IRB Approval

Office of the Vice President
For Research
Protection of Human Subjects
Review Board

1865 THE UNIVERSITY OF MAINE

418 Corbett Hall
Orono, Maine 04469-5717
Tel: 207-581-1498
Fax: 207-581-1300
www.umaine.edu

MEMORANDUM

TO: Leonard Kass
100 Murray Hall

FROM: Gayle Jones
Assistant to the Institutional Review Board for the Protection of Human Subjects (IRB)

SUBJECT: "The PC Monitor as a Visual Stimulator for Educational Studies," #2008-02-06

DATE: June 17, 2016

The Institutional Review Board for the Protection of Human Subjects (IRB) conducted its continuing review of the above referenced project in an expedited review on 6/16/2016. The IRB approved renewal, and the approval period is now through 6/22/2017. The next continuing review of this project must be conducted by the IRB before the end of the approval period. Although you will receive a request for review information approximately 6-8 weeks before that date, it is your responsibility to submit review information before the approval period expires.

Enclosed are approved copies of the consent documents for this project. The consent forms are approved for use through 6/22/2017. **These approved copies must be duplicated and used when enrolling subjects during the approval period.**

Please remember that each subject must be given a copy of the informed consent document. Any unanticipated problems or injury to the subject must be reported to the IRB. Any proposed changes to the research must be approved by the IRB **prior** to implementation. Any significant new findings must be reported to the subject.

If you have any questions, please contact me at 1-1498. Thank you.

Appendix B: **Informed Consent**

Informed Consent Form
For Subjects 18 years or older participating in this study

You are invited to take part in a research project. It is conducted by or under the direction of Dr. Len Kass, a vision scientist in the School of Biology and Ecology, at the University of Maine.

Purpose of study: To examine the way the eye works and to develop a school science exercise.

What you will be asked to do: You will be asked to look at objects on a wall, several sheets of paper, and on a computer screen. You will be asked to report what you see by responding orally, by marking on papers, or by pressing keys on a keyboard.

Time it takes to complete study: This will take about an hour of your time. After that you have the option to continue with an additional 10-30 minute test. ***You may stop at any time or for any reason.*** This is completely voluntary on your part.

Risks: Except for your time and inconvenience, there are no risks involved with participating in this experiment.

Benefits: You may find this study interesting and educational because we will be testing your very own visual system! The results will help us understand how we use our eyes to see things. Eventually, we also think this project would be of interest for use in Science as well as Science Education classes in various K-16 classroom settings.

Compensation: When applicable, course or educational credit will be given for participation.

Confidentiality: Your identity will be kept confidential. A number will be assigned to your file containing all of your responses. The data and key linking your name to data will be stored separately in the office and laboratory of Dr. Len Kass, 104a Murray Hall, School of Biology & Ecology, University of Maine. The data and the key will be kept for four years from the date of your participation, then destroyed.

Contact Information: Contact Dr. Len Kass (ph: 581-2567; email: Len.Kass@umit.maine.edu), 100 Murray Hall, School of Biology and Ecology, University of Maine, Orono, ME 04469 with any questions concerning this research and educational project.

Other Contact Information (and for any other concerns or questions):
Contact Gayle Jones (ph: 581-1498; email: Gayle.Jones@umit.maine.edu), Assistant to the University of Maine's Protection of Human Subjects Review Board, with any questions about all rights as a research participant.

University of Maine Institutional Review Board Approved for Use through 06/22/2017

Appendix C: Guardian Informed Consent

Parent and Guardian Informed Consent Form

Everyone from 5 years to adult is invited to take part in a research project. It is directed by Dr. Len Kass, a vision scientist in the School of Biology and Ecology, and by Dr. Janice L. Pelletier, a pediatrician and research scientist, also affiliated with the University of Maine.

Purpose of study: To examine the way the eye works and to develop a school science exercise. As well, students like your son/daughter might be the experimenter for their vision study.

What your child will be asked to do: He/she will be asked to fill-in a short survey or questionnaire, look at objects on a wall, several sheets of paper, and objects on a computer screen. He/she will be asked to report what they see by speaking, marking on papers, or by pressing computer mouse buttons or keys on a computer keyboard. An example of one of the survey questions is: "What is the color of your eye(s)?". All responses will be kept confidential.

Time it takes to complete study: This project takes less than an hour of your son/daughter's time. Afterwards, they have the option to continue with an additional 10-30 minute test, but ***may stop at any time*** or ***for any reason.*** Participation in this project is completely voluntary.

Risks/Costs/Payments: Except for time and inconvenience, there are no risks involved with participating in this project. There are no costs nor payments associated with participation.

Benefits: He/she may find this vision study interesting and educational because we will be testing our own eyes! The results will help us understand how we use our eyes to see things. We also think this project helps to teach science in grade school, high school, and college. If these tests are part of a class, your son/daughter may be receiving academic or educational credit, and this might be beneficial. Otherwise, participation is of educational value only.

Confidentiality: His/Her identity will be kept confidential. A number will be assigned to file containing all of his/her responses. The data and key linking your son's/daughter's name to data will be stored separately in the office and lab of Dr. Len Kass, 104a Murray Hall, School of Biology & Ecology, University of Maine. The key and data will be kept for four years after he/she participates, then destroyed.

Where/When will these studies be conducted: If your son/daughter is participating in this project at the University of Maine, the studies will be conducted in the laboratory of Dr. Len Kass, 104a Murray Hall. If they are not conducted in the laboratory of Dr. Kass, then these studies will normally be conducted at your child's school during school days and hours. The specific location and approximate dates/times are listed at the bottom of the next page.

Contact Information: Contact Dr. Len Kass (ph: 581-2567; email: Len.Kass@umit.maine.edu), 100 Murray Hall, School of Biology and Ecology, University of Maine, Orono, ME 04469 with any questions concerning this research and educational project.

Other Contact Information (and for any other concerns or questions): Contact Gayle M. Jones (ph: 581-1498; email: Gayle.Jones@umit.maine.edu), Assistant to the University of Maine's Protection of Human Subjects Review Board, with any questions about all rights as a research participant.

Parent/Guardian Consent of vision study directed by Drs. Len Kass and Jan Pelletier

PLEASE RETURN THIS SIGNED PAGE AS SOON AS POSSIBLE. THANKS!

YOUR SIGNATURE INDICATES THAT YOU HAVE READ AND UNDERSTAND THE ABOVE INFORMATION, THAT YOU HAVE DISCUSSED THIS STUDY WITH THE PERSON OBTAINING CONSENT, THAT YOU HAVE DECIDED TO PARTICIPATE BASED ON THE INFORMATION PROVIDED, AND THAT A COPY OF THIS FORM HAS BEEN GIVEN TO YOU.

Location where the study will take place: _____

Approximate dates and times the study will take place: _____

Print child's name here: _____

_____ _____

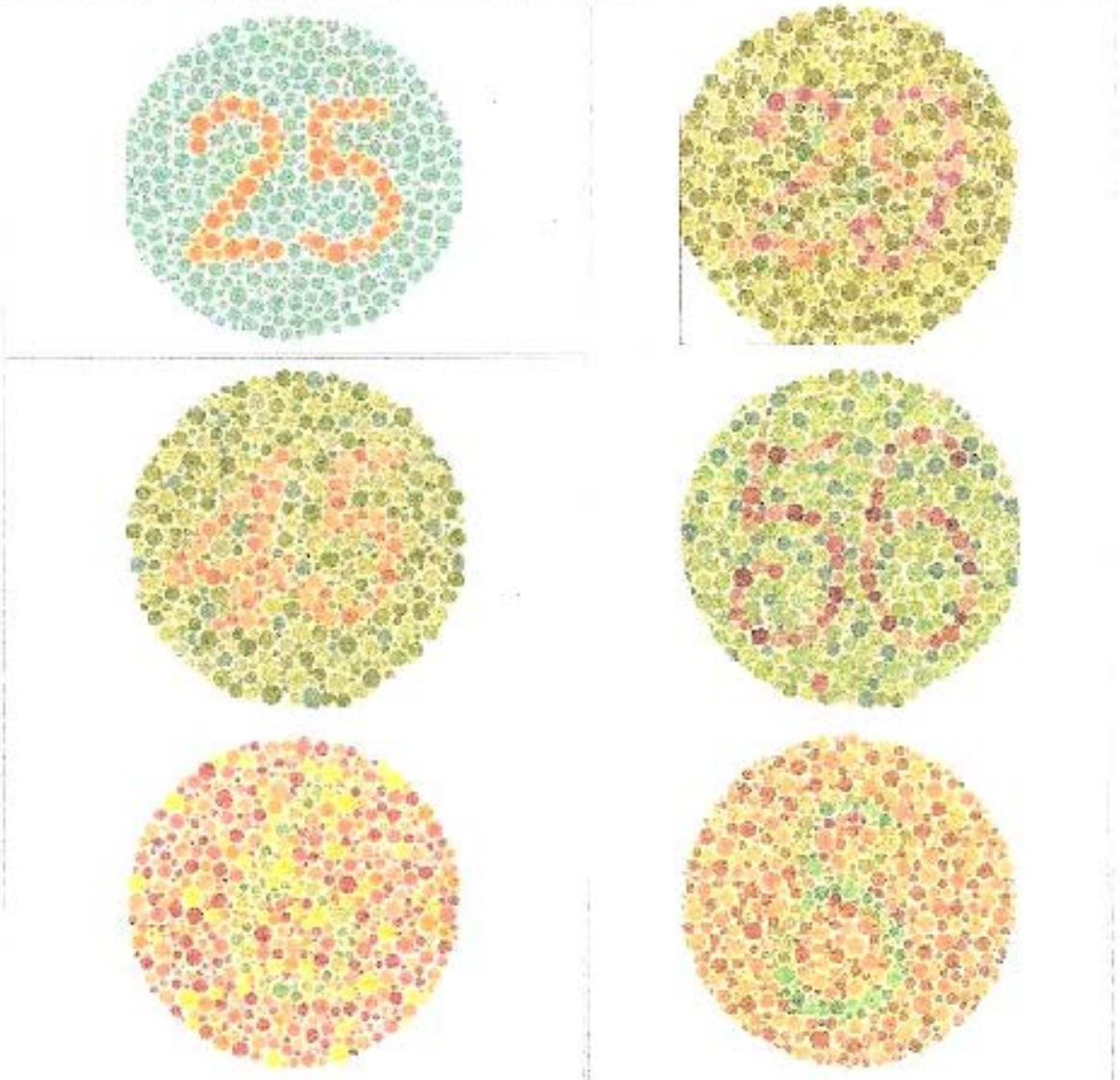
Signature of Parent, Guardian or Conservator **Date**

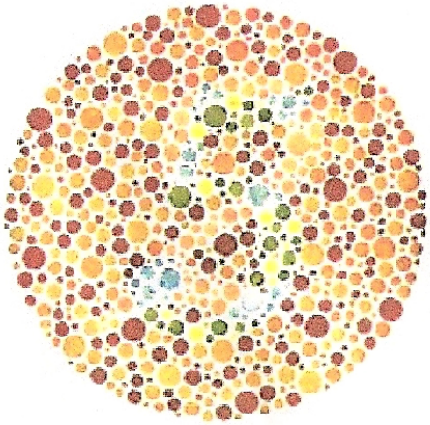
Appendix D: Ishihara Test for Color Blindness Used

Ishihara Test for Color Blindness

Main Page About Color Deficiency Tests for Color Blindness
Shareware software for the color blind About the Color Charts
Basic Black/Grays Basic Blues Basic Browns Basic Greens
Basic Oranges Basic Purples Basic Reds Basic Off-Whites Basic Yellows
Hex Color Chart Links to other Sites about Color Deficiency

What numbers do you see revealed in the patterns of dots below?





The test to the left is simpler. The individual with normal color vision will see a 5 revealed in the dot pattern. An individual with Red/Green (the most common) color blindness will see a 2 revealed in the dots.

Appendix E: Instructions for Test Subjects to run Open Door

Instructions for Running VISION 5.0 Experiments (any station) 13Feb2017

1. On the computer Desktop (or perhaps within the "V5 ..." folder), click on assigned "**Set #x**".
2. Click on the "**acuity2**" file. And follow the screen prompts for steps 3-5 below.

---

3. Enter your assigned (2-3 digit) "**Subject ID #**". Hit "**Enter**" key for all entries here & below.
4. Enter "**2**" (or any **number**) for the "**Distance**", "**Screen Width**", and "**Screen Height**".
5. **BEFORE YOU HIT THE ENTER KEY** to start the experiment: (Room Light ON, door closed)

---

a. Make sure you feel comfortable and your chin and forehead are resting on the head holder.
b. Grab joystick in one hand and stabilize it with other. Make sure red buttons face forward.
c. When you see the BOX appear on the screen, find an opening in center of one of its 4 sides.
d. Move the joystick FULLY in the direction of the opening (Up, Down, Left, or Right side).
e. The Box should disappear after you fully move the joystick and you will hear a click.
f. If you do NOT see the displayed BOX immediately disappear, FULLY move joystick again!
g. You have 3 sec to respond to each BOX. After 1.5 sec without a response, a BEEP may occur.
h. You **MUST RESPOND** to each BOX Opening with joystick moves UP, DOWN, LEFT, RIGHT.
i. IF you think there is NOT AN OPENING, you **may hit either of the red buttons in front.**

---

6. There are 12-15 expts, and after each one REPEAT STEPS 3-5 above until program ends.

If you are kicked out of the program, re-start with Step 2 above and continue.

If you did NOT finish the 12-15 expts (or other problems) just tell the Lab Assistant.

Just come out of the room when you are done or if you have run out of time and must leave.

Thank you! Never use a cell phone while running these experiments! Much appreciated!

Appendix F: Pre-examination sheet with Confidential Questionnaire

Vision Experiments **DATA SHEET** Feb. 17 Subject ID#: _____

Subject Name: _____ Today's Date: _____ Time: _____

Informed Consent Form: Read: Y / N and Signed (if <18 years): NA / Y / N

Confidential Questionnaire: Completed: Y / N Any Impairments RE ? _____

Ishihara Test for color deficits: 1: ___ 2: ___ 3: ___ 4: ___ 5: ___ 6: ___ / 7: ___

Color of your Iris: Please refer to the 998 eye chart provided and indicate your closest iris color match (ex: A20, T07, etc) here: _____

Landolt C test : Distance to Chart =13 ft (4m) BEGIN on Line where 1 MISS occurs

Make sure they use corrective lenses. Abbreviate: U =up; D =down; L =left; R =right

Line # 7: Guesses: _____ _____ _____ _____ _____ : #__/5

Line # 8: Guesses: _____ _____ _____ _____ _____ : #__/5

Line # 9: Guesses: _____ _____ _____ _____ _____ : #__/5

Line # 10: Guesses: _____ _____ _____ _____ _____ : #__/5

Line # 11: Guesses: _____ _____ _____ _____ _____ : #__/5

Line # 12: Guesses: _____ _____ _____ _____ _____ : #__/5

Line # 13: Guesses: _____ _____ _____ _____ _____ : #__/5

Line # 14: Guesses: _____ _____ _____ _____ _____ : #__/5

WHICH Open Door Set # was SUBJECT tested? _____ At WHICH STATION #? ___

Confidential Questionnaire for Vision Tests Feb.2017

Gender (circle): Male or Female Age: _____

Do you wear corrective lenses? Y or N

Are you currently wearing those lenses? Y or N

Have you ever had corrective eye laser surgery? Y or N

Do you have any visual limitations or impairments (e.g. color blindness)? Y or N

If so, please explain: _____

How many HOURS have you spent on the computer today before now? _____ hrs

How many hours/day on the computer is typical for you? _____ hrs

Fitzpatrick Category A (please circle all that apply)

Score	0	1	2	3	4
What are the color(s) of your eyes?	Light blue, grey, or green	Blue, Grey, or Green	Blue	Dark Brown	Brownish Black
What is the natural color of your hair?	Sandy Red	Blond	Chestnut/ Dark Blond	Dark Brown	Black
What is the color of your skin? (Non-exposed areas)	Reddish	Very Pale	Pale w/Beige Tint	Light Brown	Dark Brown
Do you have any freckles on unexposed areas of skin?	Many	Several	Few	Incidental	None

Fitzpatrick Category B (please circle all that apply)

Score	0	1	2	3	4
What happens when you stay in the sun too long?	Painful Redness, Blistering, Peeling	Blistering Followed by Peeling	Burn Sometimes Followed by Peeling	Rare Burns	Never Burned
To what degree do you turn brown?	Hardly or not at all	Light Color Tan	Reasonable Tan	Tan Easily	Turn Dark Brown Quickly
Do you turn brown after sun exposure?	Never	Seldom	Sometimes	Often	Always
How does your face react to sun exposure?	Very Sensitive	Sensitive	Normal	Very Resistant	Never had a Problem

---

For office use only:

Category A Subtotal: _____ Category B Subtotal: _____ Total Score: _____

Appendix G: CURE Report

Fall 2015 CURE Report
A Collaborative Project Funded by HHMI

The CURE survey offers a comparison of learning benefits between course experiences and undergraduate research experiences. The pre-course survey collects student data based upon demographic questions, reasons for taking the course, level of experience on various course elements, science attitudes, and learning style. The post-course survey parallels the pre-course survey and includes additional questions that focus on student estimates of learning gains in specified course elements, estimates of learning benefits that parallel questions in the SURE surveys, overall evaluation of the experience, and science attitudes.

David Lopatto
Leslie Jaworski

Fall 2015 CURE Report (Post-only)
A Collaborative Project Funded by HHMI
Summary for **University of Maine - Orono** (BIO 388)

	Your Students PostCourse	*All Students** PostCourse
N**	5	4296

** The data from "all students" in this report was obtained from the CURE Survey between June 1, 2015 - Jan 4, 2016*

*** N represents the total number of respondents. Note that not every respondent answered each question in the survey, resulting in Ns smaller than the total (participation) postcourse N. In such instances, the total is represented by a lower case n.*

Demographics

	Your Students PostCourse	*All Students* PostCourse	**Gender**
	3	1532	**Male**
	2	2671	**Female**
n	5	4203	

	Your Students PostCourse	*All Students* PostCourse	**Ethnicity**
	0	2	**Alaskan Native**
	0	42	**American Indian**
	0	536	**Asian American**
	0	288	**Black or African American**
	0	37	**Filipino**
	0	77	**Foreign National**
	0	3	**Hawaiian**
	0	293	**Hispanic/Latino**
	0	3	**Pacific Islander**
	4	2542	**White**
	1	218	**Two or more races**
	0	81	**Other**
n	5	4122	

	Your Students	*All Students*	**Current Status**
	PostCourse	PostCourse	
	0	6	**High School**
	0	1375	**First-year college student**
	0	1095	**Second-year college student**
	0	827	**Third-year college student**
	5	842	**Fourth-year college student**
	0	27	**Graduate or medical student**
	0	65	**Other**
n	5	4237	

Academic Information

	Your Students	*All Students*	**Declared Major**
	PostCourse	PostCourse	
	5	3406	**Yes**
	0	863	**No**
n	5	4269	

	Your Students	*All Students*	**Considering Science Major**
	PostCourse	PostCourse	*(excludes those already science majors)*
	n.a.	493	**Definitely yes**
	n.a.	206	**It is likely**
	n.a.	82	**I'm not sure**
	n.a.	40	**It is unlikely**
	n.a.	25	**Definitely no**
n	*n.a.*	846	

PostCourse Survey: Post-Graduate Plans

	Your Students	*All Students*	%	
	1	475	12.7%	**I have not considered post-graduate education**
	0	98	2.6%	**I now plan NOT to pursue post-graduate education**
	0	758	20.3%	**I now plan to pursue a Master's degree in science field**
	0	777	20.8%	**I now plan to pursue a Doctoral degree in science field**
	0	177	4.7%	**I now plan to pursue a Master's degree in non-science field**
	0	64	1.7%	**I now plan to pursue a Doctoral degree in non-science field**
	3	1316	35.3%	**I now plan to pursue a medical degree**
	0	64	1.7%	**I now plan to pursue a law, architectural, or other degree**
n	4	3729		

Course Elements

25 items about course elements

On the pre-course survey, students were asked to assess their prior experience on each element. They were asked to rate their experience on a scale where 1 means no experience or that the student feels inexperienced and 5 means much experience or that the student feels that she or he has mastered the element. These data are most useful, first, descriptively, and second, as covariates that aid in the interpretation of other data. On the post-course survey, the students were asked to "rate the gains you may have made as a result of taking this course." The 5-point scale, where 1 = no or very small gain to 5 = very large gain, is consistent with the scale used to rate other learning gains.
Means are used to represent the data.

Your Students	***All Students***	
PostCourse Gain	PostCourse Gain	
3.67	3.27	**Scripted lab or project where students know outcome**
3.33	3.33	**Lab or project where only instructor knows outcome**
3.25	3.33	**Lab or project where no one knows the outcome**
3.50	3.65	**A least one project assigned and structured by instructor**
4.25	3.83	**A project where students have input into process or topic**
4.50	3.52	**A project entirely of student design**
3.75	3.38	**Work individually**
3.33	3.22	**Work as a whole class**
3.67	3.89	**Work in small groups**
3.75	3.91	**Become responsible for a part of the project**
3.75	3.62	**Read primary scientific literature**
3.50	3.45	**Write a research proposal**
4.00	3.86	**Collect data**
3.75	4.01	**Analyze data**
3.25	3.57	**Present results orally**
4.25	3.72	**Present results in written papers or reports**
3.00	3.32	**Present posters**
2.33	3.30	**Critique work of other students**
3.33	3.58	**Listen to lectures**
4.00	3.12	**Read a textbook**
3.33	3.53	**Work on problem sets**
3.00	3.35	**Take tests in class**
3.67	3.58	**Discuss reading materials in class**
3.00	3.40	**Maintain lab notebook**
2.67	3.12	**Computer modeling**

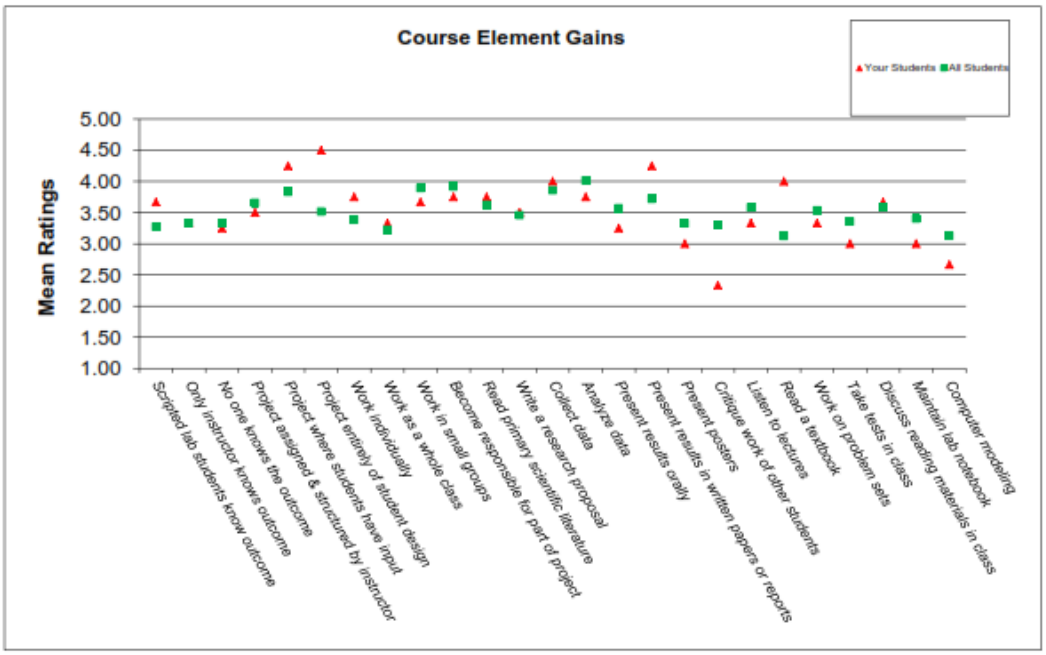


Figure 1. The figure illustrates the mean ratings by students of gains in 25 areas corresponding to the course elements above.

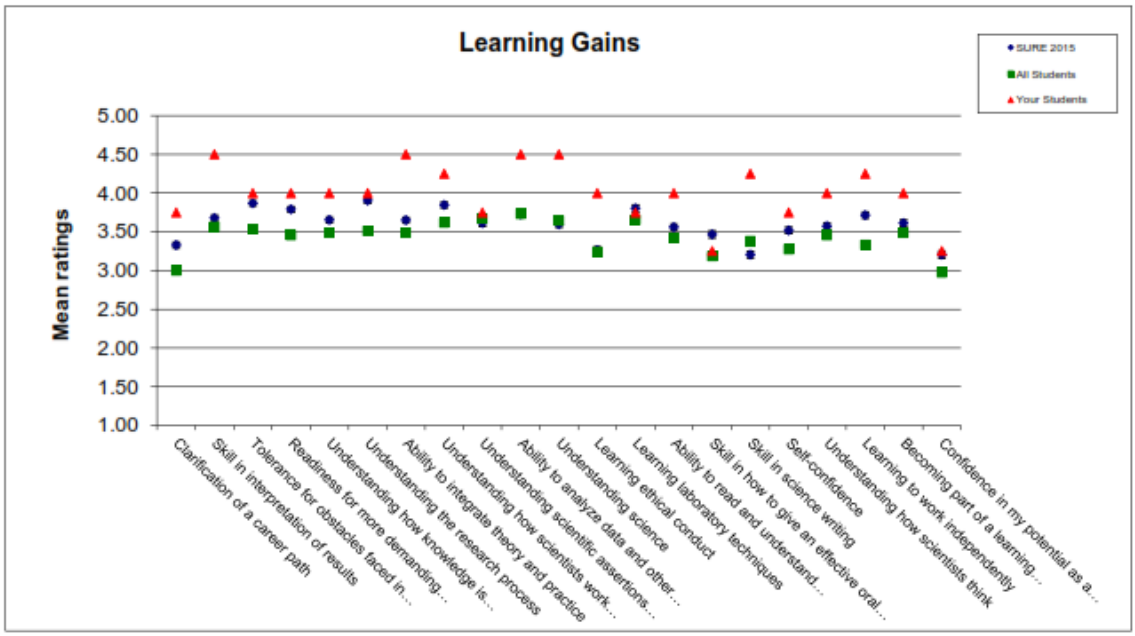


Figure 2. The figure illustrates the mean ratings by students of gains in 21 areas, corresponding to the areas above. As these same items are evaluated by students who participate in summer undergraduate research, the recent results of the Summer Undergraduate Research Experience (SURE) survey are presented for reference. Also presented (green squares) are the overall mean ratings by the reference cohort of students who completed the CURE survey in the fall of 2015. The vertical lines around the SURE means represent 2 standard errors above and below. Note: Data from students who completed the pre-course survey and those who did not are indistinguishable.

Attitudes about Science

22 questions about science

These items appear on both the pre-course survey and the post-course survey. The scale is 1 (strongly disagree) to 5 (strongly agree). We have not found large changes from pre- to post-course survey. Note that 5 items are printed in italics. In exploratory factor analysis these 5 items load on a factor that we have named "engagement". Engagement scores, whether pre-course or post-course, have correlated in our first findings with higher reported learning gains and a greater likelihood to declare a science major. *Means are used to represent the data.*

Your Students	*All Students*	
PostCourse	PostCourse	
4.60	4.23	*Even if I forget the facts, I'll still be able to use thinking skills learned in science*
3.20	3.35	You can rely on scientific results to be true and correct
4.60	3.98	*The process of writing in science is helpful for understanding scientific ideas*
3.20	3.10	When scientific results conflict with my personal experience, I follow my experience in making choices
2.80	2.40	Students who do not major/concentrate in science should not have to take science courses
3.20	2.90	I wish science instructors would just tell us what we need to know so we can learn it
2.00	2.01	Creativity does not play a role in science
2.00	2.12	Science is not connected to non-science fields such as history, literature, economics, or art
2.80	3.03	When experts disagree on a science question, it's because they don't know all the facts yet
4.60	4.23	*I get personal satisfaction when I solve a scientific problem by figuring it out myself*
3.60	2.70	Since nothing in science is known for certain, all theories are equally valid
3.40	3.14	Science is essentially an accumulation of facts, rules, and formulas
3.40	4.01	*I can do well in science courses*
3.20	3.22	Real scientists don't follow the scientific method in a straight line

Attitudes about Science (cont.)

Your Students PostCourse	*All Students* PostCourse	
2.80	2.76	There is too much emphasis in science classes on figuring things out for yourself
2.80	2.55	Only scientific experts are qualified to make judgments on scientific issues
2.00	2.14	Scientists know what the results of their experiments will be before they start
4.80	4.13	*Explaining science ideas to others has helped me understand the ideas better*
3.40	3.29	Main job of the instructor is to structure the work so that we can learn it ourselves
2.80	2.82	Scientists play with statistics to support their own ideas
4.00	3.68	Lab experiments are used to confirm information studied in science class
1.80	1.93	If an experiment shows that something doesn't work, the experiment was a failure

PostCourse Survey: Overall Assessment

These four questions serve as an overall assessment of the course. Note that the scale is 1 (strongly disagree) to 5 (strongly agree). The questions are on the post-course survey only. *Means are used to represent the data.*

Your Students	*All Students*	SD	
4.25	4.06	0.99	**This course was a good way of learning about the subject**
4.25	4.03	1.04	**This course was a good way of learning about the process of scientific research**
3.75	3.87	1.13	**This course had a positive effect on my interest in science**
4.50	4.10	1.00	**I was able to ask questions in this class and get helpful responses**

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Appendix H: Questions for Interviews

<u>Questions for Bio 388 Students</u>

A. What were some of your favorite parts of this course? What are things that we should keep doing in the course?

B. Here is a list of conceptual thinking and skills that we hoped were developed during the course.

> Which do you feel proficient in now? Were there any specific events or lessons that you think really helped you become proficient?
>
> Which would you like more time to practice with?
> Are there any other concepts/skills that you developed during the course?

C. What were some of the things you feel we could modify, improve, or stop doing in the course?

D. Do you have any ideas for things we could start doing in the course? This can include concepts or skills introduced, teaching techniques, anything you can think of.

E. To what extent did you learn new laboratory or field techniques, skills, or processes during this capstone course?

F. How important do you think your learning of new laboratory or field techniques, skills or processes were to you?

BIOGRAPHY OF THE AUTHOR

Andrew completed his undergraduate degree from the University of Maine in 2015 with a major in Biology and a focus in pre-medical sciences and Neuroscience. Andrew started at the University of Maine in 2011 in the School of Biology and Ecology. Andrew is a candidate for the Master of Science degree in Zoology from the University of Maine in August 2017.