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Welcome to this edition of WCU Research. Our mission at the Graduate School and Research Administration is to facilitate the scholarly research objectives of our faculty, staff, and students and to foster meaningful scientific work in support of the region, the country, and the world. Scholarly and creative activities are integral to the core academic mission of the University and essential to our development as teachers.

We hope that the important work highlighted in this edition of WCU Research serves to move others to pursue new exciting journeys of discovery. This issue highlights the scholarly work of some of our outstanding faculty and staff:

In the College of Health and Human Sciences, David Hudson develops prevention and management strategies for health problems that arise from normal and pathological patterns of walking in the Human Movement Science Laboratory. Leigh Morrow-Odom sets out to develop better treatment approaches to improve language abilities of clients with aphasia and predict optimal treatment for clients based on the location of damage in the brain. Brian Byrd discusses the impact of La Crosse virus and ways to decrease its transmission.

In the College of Education and Allied Professions, Jessica Cunningham studies measurement considerations in assessment and survey instruction. John Habel and Tom Ford received a “Drop Out Prevention” grant from the North Carolina Department of Public Instruction.

In the Kimmel School, Kirill Sinchuck, John Graham, and Weiguo Yang work with metamaterial fabrication and testing capabilities through the state-funded Center for Rapid Product Realization. Here they report a realization of metamaterial structures where the speed of light can be tunable from extremely slow (c/30) to faster than the speed of light in vacuum.

In the College of Arts and Sciences, Chris Cooper and Gibbs Knotts collaborate on political science research and discover important ideas about the South today and what creates trust in governments.

In the College of Fine and Performing Arts, Professor Bradley Ulrich (School of Music) traveled to Russia for the 7th Annual International Romantic Trumpet Festival and taught a master class at the St. Petersburg Conservatory. Glenda Hensley explores how mentored research in the arts is a valuable asset to teaching and learning.

The stories in this issue of WCU Research highlight the important work and achievements of our faculty and the significance of their work for our communities. The Research Administration staff oversees the planning and approval of grants and contracts needed to support projects like these. Transforming the economy of the region through high-quality research and scholarship to promote the highest level of education and training is the purpose of the Graduate School and Research Administration. We hope you will be inspired by these stories, and take advantage of the services we offer to further your own scholarly and creative activities.

Scott Higgins, Ed.D.
Dean of Graduate School and Research
Adhering to high standards for instrument development is essential for both assessments and surveys. Clearly, attention must be given to content of the instrument, but measurement properties of an instrument are crucial in determining accuracy and stability of the measures. Attention to measurement properties is typically seen in large-scale assessment, but not as prevalent in classroom assessment and survey research. The objective should be to uphold the same standards for measures in the social sciences as in the physical sciences. Rasch measurement has been argued to encompass “a set of rigorous prescriptions for what scientific measurement would be like if it were achieved in the social sciences” (Bond, 2003, p. 179). This study highlights measurement considerations in assessment and survey construction that when balanced with content improves quality of the measures. Findings from the pilot should be reported to the research team after, and updates are made to the instrument driven by theory combined with quantitative measurement. Results from this study provide a methodology illustrating the importance of informing science educators through educational measurement for constructing a quality instrument.

Objective

A foundational component to constructing a quality instrument is the process involved in its development. The purpose here is to illustrate the usefulness of the Rasch model in developing, as well as revising, an assessment and a survey instrument for a distance learning teacher training for middle school science teachers titled Newton’s Universe. The following questions guide this study:

1) In what ways can the Rasch model be useful in guiding revisions to an instrument?

2) How can it be determined whether revisions improved the instrument?

During instrument development the Rasch model is employed to guide revisions to each instrument in an effort to strengthen accuracy and stability of the measures. Furthermore, the Rasch model is used to compare the stability of the measures from the initial to the revised version of the instrument. Finally, this study provides a model where an audience not proficient in item response theory can remain involved throughout the instrument development process.
Theoretical Framework
Although classical test theory has been prevalent for much of the 20th century, item response theory (IRT) has become increasingly propagated in recent years in educational and psychological measurement applications. The Rasch model, mathematically the one-parameter IRT model, has been argued to encompass “a set of rigorous prescriptions for what scientific measurement would be like if it were achieved in the social sciences” (Bond, 2003, p. 179), including objective abstractions of equal units that are reproducible and additive (Bond & Fox, 2001). An example is the way to transform ordinal, Likert-type response rating scales into equal interval scales using the Rasch Rating Scale Model (Andrich, 1978). A fundamental expectation of the Rasch model assumes item difficulty (or item endorsement in survey research) is the only characteristic affecting person responses, and likewise person ability is the only characteristic influencing item difficulty estimates (Linacre, 1999). Secondly, a more able person should have a greater probability of success on items than a less able person. With surveys the expectation of the Rasch model is that a person endorsing a more extreme statement has a higher probability of endorsing less extreme statements (Wright & Masters, 1982).

Validity and reliability of measures can be examined through the application of Rasch measurement. The comparison of theoretical and empirical hierarchies in Rasch measurement investigates construct validity for an instrument (Wright & Stone, 1979). Smith (2004) recommends examining whether items are spaced evenly along the difficulty continuum of the variable and span at least as wide as the range of student abilities. To inspect content validity fit statistics indicate how well the data fits the expectations of the Rasch model; specifically higher performing students should be more likely to answer items of greater difficulty correctly than lower performing students.

In examining reliability, Rasch measurement produces a standard error (SE) for each person and item, specifying the range within which each person’s empirical ability and each item’s empirical difficulty fall. The individual errors are then used to produce a more accurate average error variance for the sample. In this study the researchers utilized these characteristics to examine the reliability and validity of the Newton’s Universe instruments.

Methods
INSTRUMENTATION
The instruments referenced in this study provide an example of how science educators and measurement experts collaborate throughout the development process to improve accuracy and stability of measures. First, the student assessment constructed by the research team of science educators is comprised of 41 multiple choice items with four answer choices. The items on the assessment were categorized into five topics encompassed by understanding of heat, specifically: foundations, properties of matter, energy transfer, phase change and thermal energy. The survey was designed by science educators with

1 Newton’s Universe funded by the National Science Foundation Grant No. 0417768 (J. Osborn, P.I.) Further information can be found at the project website: http://www.uky.edu/NewtonsUniverse.
feedback from survey researchers to determine teachers’ perceptions concerning past experience with professional development, practiced pedagogy, efficacy in science content knowledge, current levels of understanding with heat and temperature concepts, learning environment, and teaching style.

**RESPONSE FRAME**
The student assessment was piloted with a group of middle school students participating in a summer science camp. The assessment provided 19 completed student exams for the calibration process. Although Wright & Stone (1979) recommend the goal of at least 30 for stable calibrations, a sample of 19 students was the largest number available for the pilot.

Middle school science teacher participants were chosen from the sampling frame of public high schools in Appalachia. Researchers recruited forty-one voluntary participants for the Newton’s Universe distance learning course from the southeastern United States. Thirty-five teachers completed the Newton’s Universe course in addition to the survey instrument. Participating teachers administered the updated version of the assessment to their middle school science students. Following revisions based on Rasch pilot results, data collected as a baseline measure of student understanding of heat were examined to compare the results from the pilot and baseline calibrations.

**DATA ANALYSIS**
Slightly different models are required for assessment and survey analysis. Data collected from the pilot of the multiple-choice assessment was analyzed using the dichotomous Rasch model, which is represented by

\[
\log\left(\frac{P_{ni}}{P_{ni}}\right) = B_n - D_i
\]

Here, \(P_{ni}\) and \(P_{ni}\) are the probability that person \(n\) encountering item \(i\) is observed in category 1 or 0, \(B_n\) is the ability measure of person \(n\), \(D_i\) and is the difficulty measure of item \(i\). Using WINSTEPS version 3.57.4 software, an overall partial credit model was applied to the survey. The basic mathematical expression used for constructing measures through responses to the partial credit model is log \((P_{ni}) / P_{ni-1}\)) / \(B_n\%D_i\%D_\%\) (Andrich, 1978) where \(P_{ni}\) represents the probability the person \(n\) when responding to item \(i\) would be observed in category \(k\); similarly \(P_{ni-1}\%D_i\%D_\%\) \(B_n\) is the attitude of person \(n\); \(D_i\) is the difficulty of item \(i\) with the impediment to being observed in category \(k\) relative to \(k-1\).

While the language of item difficulty for assessments is different from item endorsability for surveys, the procedures for using Rasch measurement to guide revisions to an assessment or a survey are similar in many ways with the exception of inspecting fit and function of the distracters for an assessment and fit and function of the rating scale for the survey instrument. Fit statistics are examined to indicate the extent that responses to each item are consistent with responses to other items within the construct (Smith, 2004). As suggested by Wright and Stone (2004), an accepted guideline for inspecting model fit is to highlight items to review with INFIT mean squares within one standard deviation from the average of all INFIT mean squares. Considering the Rasch model produces a difficulty measure for each item and an ability measure for each person placing items and persons along a “yardstick”, one can see where the persons fall (based on their ability or perceptions) in comparison to where the items fall (based on their difficulty or endorsability) (Wright & Stone, 2004, p.31).

Specific to surveys, it is necessary to determine whether the model provides stable and accurate measures with respect to the rating scale – specifically if the categories fit the model, if the thresholds of the rating scale indicate a hierarchical pattern, and if there are enough data in each response category (at least 10 responses) to provide stable estimates (Linacre, 2004). Rasch modeling also provides difficulty of endorsing an item and scale thresholds unique to each item while offering response patterns of the individuals completing the survey and the amount of the attitude in the individual based on empirical evidence (Andrich, 1988; Krueger & Finger, 2001; Santor & Ramsay, 1998). The thresholds for any item demonstrate the distance among the steps between numeric ratings (Bond & Fox, 2001).

In summary, first the appropriate Rasch model is employed to guide the revisions to the initial instrument based on the accepted guidelines balanced with the instrument’s content expectations. Next the appropriate Rasch model is employed to the data collected from the revised instrument. Finally, comparison in item fit and function should occur from initial to revised instrument.

**Results and Discussion**
A healthy balance between measurement and content considerations is crucial to improving the quality of measures in assessment and survey research. The following highlights some
considerations from a measurement perspective that should be a part of developing any instrument regardless of content whether it is a classroom assessment or a survey instrument.

Fit statistics can be useful in the development process in highlighting problematic items. These items may be problematic for a number of different reasons including confusing wording, misleading distracters, or not appropriate for the construct. The collaboration between measurement and content experts here is meaningful in identifying issues with these items and deciding how to approach it. Conversations of developing and revising an instrument from a content perspective are enriched by discussions that take place when the measurement perspective highlights issues from empirical evidence. While fit statistics are usually the beginning of the revision process in magnifying individual items, other components can also be examined to aid in improving the quality of measures.

Prior to administering the instrument, developers should provide an expected difficulty (or endorsability for surveys) hierarchy of the items. The empirical hierarchy of items can be compared to this expected hierarchy of items to inspect construct validity. The developers are advised to revisit any unexpected discrepancies between the two hierarchies to be certain the question adequately assesses the targeted concept. An example of an empirical hierarchy is provided in Figure 1 resulting from the pilot data for the assessment [on which students are indicated with X’s on the left side and items are indicated by their number and specific domain on the right side]. Items at the bottom of the figure indicate easier items to more difficult items as you move upward on the graph. Gaps in the item “yardstick” where a number of students are located along the continuum without items targeted at that ability level indicate where items may need to be added to span the range and better differentiate between respondents. The spread of

FIG. 1: Persons map of items for pilot data.
difficulty (or endorsability) of items can also be examined in Figure 1 across domains, which in this example are: foundations (F), properties of matter (PM), energy transfer (ET), phase change (PC) and thermal energy (TE). Notice questions highlighted in red on the item map indicate items within the same domain at the same location along the continuum. Close examination of empirical hierarchies is essential in developing a quality instrument to ensure the instrument measures what developers are intending to measure.

While these conversations are more prevalent for assessments, the same measurement standards should be upheld in developing a survey instrument. Often, surveys are viewed as an easy and quick way to gather data. On the contrary, in order to measure what is intended, the same procedures need to be followed to ensure gathering stable and accurate measures in survey research. Similar to assessments, conversations about fit statistics and empirical hierarchies need to be a part of the development process. Unique to survey development is the quality of the rating scale categories. Attention must be given to the rating scale considering that every respondent interprets the rating scale uniquely for every item. An example is provided in Figure 2 of how empirically the distances between the rating scale categories are unique for each item on the survey.

This example references survey items asking teachers to rate (1=None; 2=Minimal; 3=Average; and 4=Extensive) their current perceived levels of understanding of temperature and heat concepts covered in the distance learning teacher training. It is clear from this figure that the distances between rating scale categories are not equidistant which means in constructing and analyzing survey results adjustments must be made to ensure accurate interpretations of the data.

Rating scale categories should be fully utilized by respondents in order to ensure stable and accurate measures in survey research. Probability curves can be used to inspect whether the rating scale category function is being fully utilized by respondents. In this example, rating scale categories (none, minimal, average, extensive) used for describing perceived current levels of content knowledge were not fully being used by respondents; therefore, the suggestion was made to collapse to three, rather than four, rating scale categories for these items.

Following the reconstruction process, the research team should develop a new theoretical hierarchy of item difficulty based on the pilot results and any revisions made. Once the instrument has been administered, the research team may choose to follow up with the same procedures to ensure any changes are functioning as expected.
Conclusion

Thorough inspection of all aspects of an instrument is crucial in providing the most stable, accurate measure of the intended construct. An important lesson here is that while longitudinal measures are important, accuracy and stability of the measures should be of constant consideration. The strength of this study is the partnership of science educators in developing an instrument with researchers in educational measurement to construct quality measures. This study provided examples of a thorough, collaborative model useful in instrument development for both assessments and surveys.

Techniques from this development process illustrate efficient and effective ways to develop quality instruments that can be used in other settings. Developing quality instruments to measure the cognitive or affective domain is essential in determining whether efforts will be made to implement any knowledge gained from an intervention. This development process may support other researchers in attempts to link performance and affective outcomes to training and the continued growth of collaborative efforts between measurement and other research communities.

REFERENCES


Is the South disappearing? Does diversity reduce trust in people of different races? How does trust in government influence policy opinions? Who writes letters to the editor? These may not sound like typical questions for political scientists.

Indeed, when we got to graduate school, these were not the types of questions we thought we would be addressing. We thought we were much more likely to study elite actors who live and work in Washington – Congress, the president, and the Supreme Court.

Although we were in graduate school in different places – Gibbs at Emory and Chris at Tennessee – we both independently came to three realizations about the scientific study of politics that eventually led to our fruitful collaboration at Western. First, although questions about elite actors are important, we both decided that we
were much more interested in the actions and opinions of citizens like you and me – how do “regular people” conceive of politics and relate to politicians. Second, while national politics are no doubt important, we both believe that politics at the local and state levels are equally interesting and consequential. Third, we both realized that some of the most interesting insights about politics do not come from political scientists, but rather from psychologists, sociologists, geographers, economists and those from other disciplines.

With these three themes in mind, we have examined a number of interesting questions about human behavior. Some of this work we have conducted separately. For example, Gibbs has written an influential series of articles about the influence of precinct placement on whether someone votes, and Chris has conducted frequently cited research on the role of the media in state politics. The work that we find the most fun, however, is the work we do together. In our collaboration at Western, we have co-authored over a dozen journal articles and book chapters, over 15 op-ed pieces for newspapers, and one co-edited book. Obviously we don’t have the space to share all of these here (although we would be eternally grateful if you would buy our book – it makes a great gift) but here we would like to share three projects with you. All three of these projects were inspired by what we see every day as residents of western North Carolina. It’s safe to say that if we had a job at a different school, we would never have conceived of these projects.

The Changing South

One research agenda that we have worked on together regards the American South. We are particularly interested in questions about whether the South as we know it is still distinct. People like John Shelton Reed (who Gibbs studied with as an undergraduate) made a career out of exploring what it is that makes the South different. Reed even came up with a number of interesting ways of measuring the outlines and characteristics of the South. Over the course of his career he has studied uniquely Southern characteristics including country music lyrics, kudzu growth, barbeque, and Kappa Alpha chapters.

One of Reed’s most well known studies involved his analysis of business names. Reed hypothesized that places that had a lot of businesses with “Dixie” and “Southern” in their names must be places where people identify strongly with the South. When Reed studied this in the 1970s and 1980s he found a shrinking, but still strong South. We decided that it would be interesting to reassess his earlier findings to see what had changed and what had stayed the same. We find that the number of businesses named “Dixie” has dropped considerably but that the word “Southern” has remained much more consistent. We also explain regional identity and find that a city’s percentage of African-Americans and more recently higher population densities have great identification with the region. Work on this research agenda has been published in Social Forces and Southern Cultures, and we have published related work in Social Science Quarterly, and the American Review of Politics.

Trust in Government

It’s hard to live in western North Carolina and not realize that perhaps the most controversial subject in the region is zoning. On one side are the opinions of folks like one former Macon County Commissioner who once likened zoning to Communism. On the other side are people who believe that zoning is an integral tool of local governments. Putting aside our own opinions, we began to wonder what accounted for these radically different opinions. Fortunately, thanks to a poll conducted at WCU’s Institute for the Economy and the Future, we had just the right data to answer the question. Through this survey, we had data addressing important questions for almost 1,000 people in the 23 westernmost counties. What we found was that support for zoning could be predicted by lots of things – including the time a person has spent in the region, partisan affiliation, and lots of other demographics. The biggest influence on zoning, however, is the extent to which a person trusts their local government to do what is right. Interestingly, we also found that their trust in state and national government has no influence on zoning opinions.

Together, these findings suggest some positive things for our understanding of how citizens make decisions about public policy. Our findings about the influence of trust in local government suggest that citizens are competent enough to know that local government officials are the parties primarily responsible for zoning. When they trust these officials more, they cede them more power. If a person trusts local government less, they want to give them less power. Further, the fact that trust in state or national governments does not influence opinions on zoning suggests that citizens are able to distinguish between trust in different levels
of government. These findings are reported in an article we co-authored with our colleague in Sociology, Kathleen Brennan, and were published in the Public Administration Review journal.

Letters to the Editor
During the 2004 race for the 11th Congressional district seat, we began to notice that many supporters of challenger Patsy Keever were taking to the editorial page to get their message out. Over coffee, we began to ask what we knew about editorial pages as a means of political participation – turns out the answer was not much. To us, this seemed like a real shame. After all, letters to the editor are a unique political act – they reach a large number of readers, letter-writers sign their names (and usually home towns), and the letter-writers often give the rationale for why they support a particular issue. Contrast letters with an act like voting where it is more difficult to determine why a person votes the way they do and you can see why we thought studying letters to the editor was an intriguing idea.

To learn more about the content of letters and the people who write them, we began by taking a random sample of letters from the seven largest newspapers in North Carolina. We coded the letters for lots of characteristics, including content and tone. Perhaps most importantly, we then recorded the name and hometown of every letter writer. Now here’s the clever part: with the help of our friend Moshe Haspel at Emory, we used a computer program to look up each letter-writer in the North Carolina voterfile where we could identify all sorts of interesting information about the writer like their gender, their race, the last time they voted, and their partisan affiliation.

In the end, our analyses suggest that the editorial pages of North Carolina newspapers do a fairly good job representing the interests of both liberals and conservatives – we find almost a 50/50 split between Republican and Democratic letter-writers. Unfortunately, there’s one place where our editorial pages don’t look so representative – North Carolina newspapers are much more likely to include letters written by men than women. Further, we found that women and men write very different letters – both in content and tone. We are not suggesting that this is the newspaper’s fault – indeed, newspapers can only select between letters that are sent to them. Nonetheless, we believe this is an important finding for those concerned with gender equality in American politics. These results were covered in the Raleigh News and Observer and were also written up in an op-ed in the Durham Herald-Sun and published in the academic journal, *PS: Political Science and Politics*.

Conclusion
These are just a small sampling of the projects we have worked on, but it should give you an idea of the type of work that motivates us – and, in turn, motivates our students. We would be remiss if we did not note the role Western Carolina has played in helping us develop this research agenda. Our work is explicitly interdisciplinary and we believe that the commitment to interdisciplinary thinking is a primary reason why Western Carolina is such an intellectually interesting place to work. Rather than confining our conversations to people in our own department, as we no doubt would at a different type of school, we’ve benefited greatly from the conversations we have with our friends and colleagues in history, psychology, sociology, and a variety of other disciplines. These conversations make our work more interesting, relevant, and rigorous; and most importantly, allow us to connect our work to what our students are learning in classes across campus. ✨
The Human Movement Science Lab: Steps into the Future

In 2004 the Department of Physical Therapy received a grant from the Kate B. Reynolds Foundation to develop the Human Movement Science Laboratory. The principle equipment in the lab includes eight digitally coupled cameras, two force plates embedded in the floor (Figure 1, page 12), and a foot pressure mat (Figures 1 and 2, page 12). The eight cameras simultaneously record motion of reflective markers that are placed on the person moving through the collection volume. The force plates measure vertical downward force (similar to a bathroom scale), as well as shear forces that make the foot slide forward and backward and side to side. Together these data are used to calculate the 3-dimensional motions of the body; the forces that are imposed on the hip, knee, and ankle joints; and the muscle activation patterns needed to control our movements. The pressure mat is composed of an array of small sensors that measure about two hundred regions of pressure under the foot and produce a “map” of foot pressure. Labs like ours enable researchers/clinicians to conduct basic science or translational-type biomechanical studies and perform clinical studies of dysfunctional movement to aide with surgical decision making. Most of the research in the Human Movement Science Laboratory is aimed at developing prevention and management strategies for health problems that arise from either normal or pathological patterns of walking.
On average, the people of our nation are growing older and heavier. There are a number of maladies associated with increased age and weight including osteoarthritis and diabetes. Medically managing these conditions is expensive to the individual and our government, which is ultimately the peoples’ burden. Both osteoarthritis and diabetes respond well to exercise. Walking is among the most common and effective forms of aerobic exercise. No chic fitness centers or pieces of bulky equipment that clutter the home are needed; for the price of a decent pair of athletic shoes (preferably running shoes for paved surfaces) a person can get about 400 miles worth of exercise. Aerobic exercise is energized (burns calories) by metabolizing more carbohydrates and body fat compared to sedentary activities. When performed for more than 15 minutes, fat is used as the primary source of fuel. In addition to losing weight, benefits from aerobic exercise include improved cardiovascular and pulmonary function (heart, blood circulation, and lungs), lower cholesterol, lower blood sugar (important for control of diabetes), and more restful sleep. Research has shown that for people with osteoarthritis of the knee, aerobic activity helps reduce pain and limit the decline in function associated with progression of the disease. So the question is: why doesn’t everyone who can walk do it? The answer is not the same for everyone. For some it may be because walking causes pain, or for people with diabetes it may be due to a fear of developing pressure sores on their feet.

Despite being a “low impact” exercise, biomechanical research has shown that walking places a substantial force on the soles of the feet, the joints of the legs, and the lower back. These forces occur with every step we take – up to about 125% of our body weight with normal walking speed which can increase to over 400% body weight with running. Research in our lab has identified areas of force concentration in the knee toward the inside of the joint – a reason why degenerative changes are much more common in that part of the knee (i.e., osteoarthritis or degenerative tears in cartilage). Other biomechanical studies in our lab have found areas of force concentration on the “ball of the foot,” under the biggest toe and/or one of the two smaller toes adjacent to it (Figure 2). In healthy

FIG. 1: Motion analysis of a subject walking with hiking poles. Provides kinematics (motion) and kinetics (forces) in the joints.

FIG. 2 (inset): Pedobarograph used to map pressure on the bottom of the foot.
people this can lead to pain with walking/running; but for people with diabetes this can result in open pressure sores that, if poorly managed, can lead to amputations or even death.

Current research is being conducted in the Human Movement Science Laboratory to investigate interventions aimed to reduce the harmful areas of force concentration in the arthritic knee and the diabetic foot. Graduate students in the physical therapy program are involved with two separate projects that are determining the effects that walking with poles have on knee joint function and the distribution of force on the sole of the foot (Figures 1 and 2). Walking poles seem like a very appropriate device to study in the Western Carolina region as people commonly use them for hiking, and there appears to be increased popularity for using them with “off-trail” walking.

Initial results from data collected on healthy subjects have found an approximate 26% reduction in concentrated force on the sole of the foot when walking with poles compared to without poles (p = .01). Following the completion of this study, prospective data will be collected on people with diabetes to determine if the off-loading that occurs when walking with poles can be used to either prevent wounds or aide in the healing of existing wounds.

Walking with poles also significantly reduces the harmful joint force on the inside of the knee by about 15% compared to walking without poles (p < .001). Related research conducted by other investigators has found similar reductions when walking downhill and when carrying a backpack. Walking with poles is also known to increase energy consumption without increasing the perceived intensity of the activity; so people can work harder and burn more calories without feeling as fatigued. Therefore, the work in our lab and that of other investigators has built a good case for the use of walking poles by people who either have or are at risk of developing knee osteoarthritis. Collectively, the research suggests that walking with poles may help to limit the pain, clinical progression, and loss of function associated with knee osteoarthritis.

Osteoarthritis develops from both metabolic and mechanical pathology. Advancing age and concentrated joint forces are among several mechanical risk factors for knee osteoarthritis including obesity, muscle weakness, and abnormal torsion (twisting) in the long bones of the leg. Other faculty/student research has developed a method of measuring torsion using ultrasound that is more accurate, less expensive, faster, and safer than previous methods. Subsequent studies helped identify torsion as a risk factor for knee osteoarthritis by showing that people with abnormal torsion had significantly greater hardening of the superficial bone and cartilage in the knee, a harbinger of osteoarthritis. Another study showed a correlation between the torsion in the long bones of the legs and the angle that the feet were directed while walking, and provided evidence that the torsions present in adulthood may be adaptations from childhood torsions. These findings are part of an important academic debate on the origin of adult torsional pathology and whether or not childhood torsions should be treated.

Other research being conducted in the Human Movement Science Laboratory is providing evidence for treatments and evaluative tools commonly used by physical therapists and other medical practitioners. Projects like these will play an extremely important role in the growth of the physical therapy profession and help control costs of health care. One current faculty/student project is investigating the effectiveness of different taping techniques on controlling abnormal foot motions that are responsible for numerous ailments in the legs and feet. Another project is developing a simple clinical assessment tool for the foot that reasonably predicts more complex foot function. Students are comparing several common structural measurements of the foot to functional measurements made by the more sophisticated, expensive motion analysis equipment. The goal is to identify a valid and reliable method of determining foot function that can be used by the majority of practitioners who work in clinics where full motion analysis systems are not practical.

The College of Health and Human Sciences and the Department of Physical Therapy are fortunate to have a lab with the research and clinical capabilities of the Human Movement Science Laboratory. The new Health Sciences building on West Campus will house a multidisciplinary outpatient clinic. In response to the critical needs of our country and the people of this region, the college has committed to taking on a major initiative that focuses academic, research, and clinical resources toward geriatric care. The Human Movement Science Laboratory will play an important role in that initiative by continuing to conduct research on health problems that are related to movement dysfunction in aged populations, as well as plans to offer a clinical gait analysis service.
A Spiral to Success: The Rewards of Mentored Undergraduate Research

GLENDA HENSLEY

Abstract

Mentored undergraduate research is an effective methodology by which to enhance student learning. This article presents a case report of one undergraduate student and how the process of research and creative scholarship informed and empowered her academic career. As a qualitative report, I will discuss this student’s primary research and thesis project, scholarship process, and related accomplishments. Grounded in a holistic pedagogy, my conclusions assert that mentored research in the arts is a valuable asset to teaching and learning.
Introduction: Sparks and spirals
Defined as an inquiry, investigation, or significant creative achievement conducted by an undergraduate student with a faculty member, Undergraduate research and Creative scholarship is designed to make an original intellectual or creative contribution to the discipline (modified: Council on Undergraduate Research). Mentored undergraduate research is an effective methodology by which to enhance student learning as they engage with curricular content deeply and with a purpose that can be identified, authenticated, and integrated into a wider spectrum of learning experiences. I have had the opportunity to sponsor several undergraduate research projects over the past four years at Western Carolina University. I have witnessed the positive impact on student learning with a heightened intellectual curiosity, evidenced by course work, a strong work ethic, and the ability to critically reflect upon the project and its implications for future scholarship and creative endeavors.

Teaching in the College of Fine and Performing Arts, I am grateful that our university recognizes Creative Scholarship as an equal with what could be defined as traditional research models more typical of the sciences. In the arts, our research is often disseminated via performances, exhibits, poster sessions, or a combination of the creative component with a research paper or formal presentation. As Boyer (1990) states, “... the degree to which this push for better education is achieved will be determined, in large measure, by the way scholarship is defined ... (p. xiii).” For those who work in and engage with the arts, this distinction is critical. Accepting creative scholarship as legitimate, the academy empowers students in the arts to be vigilant in their pursuit of wisdom. As a faculty member of the department of Stage and Screen, my particular areas of expertise are in costume design and educational drama (Theatre in Education being one form).

I am convinced that the performance or exhibit of any quality art representation demands research. In theatre, that fact is simply a given. Good theatre is good storytelling and one cannot do justice to the story without the requisite research upon which to ground the work. Research must precede the creative process for any play—whether historical, contemporary, fantasy, or impressionistic. It is this truth that I impress upon my students. Even if only to do what is required within the process of creating theatre, students will employ research. Significant learning occurs when students are encouraged to explore beyond the basics of fact and image documentation. By significant, I mean learning that they have identified as relevant to their goals, that challenges them to grow artistically, and to integrate new knowledge and understandings into other disciplines or co-curricular activities. The research process encourages students to purposefully engage directly with content. Additionally, the research process in the arts encourages ongoing exploration and inquiry. The combination of discovery and imagination will guide students to more questions or to reframing questions as they examine the options and refine creative choices (Wagner, 1998).

Case Study: Stories that spiral
With case study, “the interest is in process rather than outcomes, in context rather than a specific variable, in discovery rather than confirmation” (Merriam, 1998, p. 19). The intensely descriptive nature of case studies can serve to illustrate the complexities of a situation; demonstrate the influence of personality, time, and bias. They offer relevant information for the present, based on the hindsight presented. The descriptive element can be informed by a wide variety of sources, include vivid material, cover an extended period of time, and present a variety of opinions and viewpoints.

The Theatre in Education (TIE) program at Western Carolina provides students the opportunity to engage in significant learning that is grounded in research and the advancement of creative scholarship. TIE students immerse themselves into cultural, environmental, and social issues that inform their creative process and artistic productions. Placing theatre and education as equal partners, TIE programs strive for artistic excellence that is educationally driven. In 2007, the TIE company produced an original play for young audiences based on Cherokee legend. They titled their play “Dogwood’s Search.”

The costume designer for this production, Leanne Deaver, quickly realized the depth of knowledge she would need to acquire in order to create the costumes for a production that merged cultural
and historical folklore with storytelling forms appropriate for youth. Her research involved a review of historical documents, cultural records and first-hand accounts (via museums, interviews, and workshops), technical manuals, fantasy art references, children’s books, and nature studies; as well as the host of hands-on skill sets required. Leanne understood and embraced the research process to acquire the knowledge within which she could frame her designs. Because the TIE course requires a formal research paper for each student, Leanne would be well positioned to take the next step of disseminating her work in a public forum. However, as with many undergraduate students, taking the next steps would require a bit of gentle nudging from me, as her teacher and mentor. It is, after all, a huge commitment of time to formalize the research process – to move beyond the paper, journals, and bibliographical annotations in order to disseminate both the research and creative process. I stress to my students that the creative outcome will be stronger, more credible, and artistically coherent once grounded in the words that express the thoughts and interpretations. Organizing and refining the mountains of data into a defined presentation or exhibit provide such an opportunity. Knowing that the process will be held to view alongside the finished product forces the need for defining and defending choices. The preparation challenges the student to be vigilant in their ability to answer ‘why?’ The expectation is that this process will inform the next creative project – will enhance the student’s ability to think, reflect, and respond with critical awareness.

Leeanne first presented her work to the WCU Undergraduate Research Expo in the spring of 2007. In the fall of 2007, I suggested that she enter her designs and research to the United States Institute for Theatre Technology (USITT) – Southeast Regional Student Design Competition. Somewhat reluctant and a bit apprehensive, I promised Leanne that if she would enter the student competition, I would enter the faculty competition. That bargain proved to be a defining moment for both of us. As a juried exhibit, she elected to enhance her display boards and integrate more of the research process documentation. I prepared my exhibit entry, working along side Leanne in the costume shop – while we were both already deeply involved with a new production. We were both successful. Leanne was selected to represent the region in the national Design Expo to be hosted in Houston in the spring of 2008 – and I to represent faculty. I agree with Edmiston’s assertion that co-researching with students enables a tremendously successful outcome for both teacher and student (Wilhelm & Edmiston, 1998). In this case, our cooperative relationship had already expanded beyond the TIE production to include research presentation models, grant writing, and more.

With her confidence bolstered, we began to make plans for the upcoming spring conference. In the meantime, we embarked upon our next definitive adventure for the fall semester – the William Ivey Long Symposium hosted in Wilmington, NC. Mr. Long, a six-time Tony award-winning Broadway costume designer, has accumulated a host of professional accomplishments and accolades, far too long to list here. As the coordinator for the WCU student entourage, I had also been asked by Mr. Long to coordinate a museum walk-through to be videotaped and to provide my students as display set-up assistants. Naturally, we were all thrilled for the opportunity. This was Leannes’ first introduction to William Ivey Long and his team. Without question, this was an inspirational four days for all who made the journey to the Cameron Art Museum in Wilmington. Leanne would continue to recount this experience as her most significant engagement at Western Carolina.

In the spring of 2008, Leanne and I traveled to Houston to disseminate our creative works at the national conference for USITT. That journey required additional research of a different sort for Leanne – she now had to learn how to write for funding. While we may all begrudge the time grant proposals require, we also know in the arts...
that our work is dependant upon the ability to transform academic research and data to a form that will garner financial support.

Moving forward to the summer of 2008, Dogwood’s Search was invited to perform at the American Alliance for Theatre and Education (AATE) national conference. Starting with a new cast, we would need to revamp the script, props, and costumes. Leeanne, though not enrolled in the summer class, volunteered to re-vision the show and redesigned selected costumes to adapt to the re-written script and new actors. She recognized that the interpretive nature of qualitative research is a process and that theatre is a live experience in which “multiple realities are constructed socially by individuals” (Merriam, 1998, p. 4). It was evident that Leeanne had evolved her understandings and work ethic to embrace the potential – to be willing to return to research – to understand that the process is the joy. She elected to write her senior BFA thesis on this journey she shared with Dogwood – the work was excellent. The thesis supported my convictions that good art requires good research. Within Leeanne’s review, analysis, and conclusions, she referred often to the scholarship process that resulted in the creative product – that received national recognition – that prepared her for a professional career in New York.

Conclusions: Spirals have no end

With creative scholarship models that focus more on case studies, teachers and students have the opportunity to explore deeply and communicate findings richly (Wagner, 1998). As documented in other course work over Leeanne’s remaining tenure at Western Carolina, the lessons learned from engaging formal mentored research enhanced her ability to make connections across disciplines, and informed her approach to the creative projects with which she participated during her senior year – whether in the costume shop, the design lab, movie sets, or art classes. She had developed a sense of curiosity and a drive to discover new ways of communicating her ideas. As my assistant designer for Fiddler on the Roof, during her senior year, her work evolved from reflecting ideas to the aims of synthesis learning – she was visioning new ways to approach the creative process and implementing them. With an emphasis on holistic forms of analysis, qualitative methods offer a wider lens through which to observe and understand the focus of inquiry, as it reveals how the parts work together to form the whole. The arts offer an interpretive and creative experience allowing for multiple realities as expressed or experienced by the participants and observers. Leeanne had embraced the whole with new perspectives and insightful reflection.

As we entered the closing chapter of Leeanne’s academic career at Western Carolina, I was witness to the dominant question that dominates many sleepless nights – ‘What now?’ Once again, I found myself fortunate to be a mentor and teacher. Leeanne asked me if I would write a letter of reference for her to apply for a summer internship with William Ivey Long. This was not a difficult choice for me, knowing that she was ready. She had repeatedly demonstrated her commitment to excellence, her sense of organization, willingness to learn, and a work ethic that consistently goes above and beyond. The happy ending is that she was accepted – the happier ending is that she excelled to the point of securing professional work offers immediately upon her internship completion, most recently working with William Ivey Long again – but this time as a young professional working on the musical, Dream Girls.

I had the opportunity to have many conversations with Leeanne and William’s associate, over the term of her internship. She was deemed superior for her attention to detail, work ethic, and ability to comprehend situations, assess the needs, and act upon those needs. She demonstrated repeatedly her ability to adapt, to discover what she did not yet know, and to ask good questions. At the end of the day, this is what a good researcher does. I am firmly convinced that the process of mentored scholarship contributed to Leeanne’s ability to spread her academic and creative wings and provided her a foundation grounded in the pursuit of knowledge and wisdom.

REFERENCES


DROP OUT PREVENTION:
Reducing Unintentional Racism and Stereotype Threat in Elementary School
A Series of Courageous Conversations

JOHN HABEL and TOM FORD
Psychology

The original creation of racial categories was in the service of oppression. Some may argue that to continue to use them is to continue that oppression. I respect that argument. Yet it is difficult to talk about what is essentially a flawed and problematic social construct without using language that is itself problematic. We have to be able to talk about it in order to change it.

Excerpted from: Beverly Tatum, “Why are all the black kids sitting together in the cafeteria?” and other conversations about race.
John Habel and Thomas Ford of the Department of Psychology, with the assistance of graduate student Leah Edwards, have received a “Dropout Prevention” grant from the North Carolina Department of Public Instruction (NCDPI) to work with members of the faculty and staff at Isaac Dickson Elementary School in Asheville and Alida Woods, Principal of Dickson. Inspired by Beverly Tatum and others who address the challenges in schools that contribute to underachievement among students of minority status, the project, which those at the school have dubbed “Courageous Conversations,” is designed to help educators at Dickson learn to create environments in their classrooms and throughout the school that are sensitive to the unique experiences of their students who might otherwise be subjected to the subtle effects of unintentional racism and stereotype threat.

The size of the NCDPI grant is approximately $73,000. Additional in-kind contributions from Isaac Dickson Elementary School, the Asheville City Schools, and the Department of Psychology at WCU total approximately $50,000. Begun in January 2009 and funded through August 2010, Habel and Ford’s project is based on the premise that teaching educators about both the not-so-obvious debilitating effects of unintentional racism and stereotype threat, as well as methods of intervention designed to counter those effects, can promote the general goals of greater student learning, achievement and retention.

Underachievement and Dropping Out among Students of Minority Status

The Courageous Conversations project is designed to address the unique social and psychological challenges in schools that contribute to underachievement and dropping out among students of minority status. The dropout rate and poor academic achievement of students of minority status is, at least partially, due to educational environments that uniquely threaten or challenge these students. Accordingly, the project addresses “at risk environments” rather than “at risk kids.” Its focus is on changing the prevailing culture of the school through interventions that directly target the knowledge, dispositions and behaviors of educators rather than on changing the behavior of particular students.

Students of minority status, particularly African-American and Hispanics, exhibit poorer attendance and dropout of school at higher rates relative to Whites (e.g., Dei, 2008). According to the NCDPI, African-American students and other students of minority status were over-represented in 2006-2007 dropout rates, as they were in previous years. The state’s grade 9-12 dropout event rate in 2006-2007 was 5.25 percent. African-American students, however, dropped out at a rate of 6.16 percent. In the Asheville City Schools in 2006-2007 African-American students also were
over-represented among dropouts; 45 percent of the dropouts were African-American students, while African-American students comprised only 42 percent of all students in the system.

Unintentional Racism
Researchers have identified racism as at least partially to blame for dropout rates among students of minority status. In contrast to students of minority status, who are acutely aware of how racism affects the social climate of schools, White teachers are less likely to perceive racism in education (Dei, 2008; Donaldson, 2001). Donaldson (2001) writes, “Their [White teachers’] lack of self-awareness, their racist conditioning and their failure to recognize the racist experiences of others impeded their recognition of racism in education” (p. 6). Thus, White educators sometimes can unintentionally exhibit subtle racial biases that disadvantage minority students.

Consequently, Habel and Ford look not at teachers’ intentions and personalities to identify racism, but at the potentially biased consequences of their behavior and thought processes. Following Gaertner and Dovidio’s (1986) theory of aversive racism, Habel and Ford propose that to varying degrees, genuinely egalitarian teachers can unconsciously harbor both negative emotional reactions (e.g., uneasiness, anxiety) to students of minority status and make stereotypical associations among minority students and negative personality traits. Devine (1989), for instance, found that, independent of their personal beliefs, Whites developed associations among African-Americans and traits such as “athletic,” “criminal,” “unintelligent,” and “violent.”

These negative emotions and stereotypical trait associations can act like sunglasses that color how teachers think about and respond to minority students. They can lead teachers to act inconsistently toward minority students. Sometimes teachers whose racial attitudes are characterized by ambivalence act in a fair, unbiased manner, but at other times (when biased behavior can be rationalized or passed off as not racist) they may exhibit subtle discrimination. For instance, research has shown that White teachers tend to hold lower expectations of their minority students. They also are more likely to attribute poor academic performance to lack of ability for their minority students, than for White students. In addition, they tend to provide more positive feedback on mediocre work to minority students than they do White students. For students of minority status these inconsistencies can create a climate in school of suspicion, confusion, distrust and bias.
Stereotype Threat

In addition to unintentional racism in school, students of minority status also must contend with the challenge of “stereotype threat.” Steele and Aronson (1995) assert that the mere existence of negative stereotypes alleging intellectual or academic inferiority creates performance pressures for minority students that non-minority students do not experience. Students of minority status must contend with the threatening possibility that should their school achievement falter, it could confirm the stereotype and reduce them to that stereotype either in their own minds or in the minds of their teachers. So, if they do poorly they become vulnerable to the implication of the stereotype that they are generally inferior simply because of their minority status. Consequently, stereotypes of academic inferiority create a challenging, intimidating social environment for students of minority status.

Wise Criticism

Seventeen teachers at Dickson are participating in workshops and collaborating with Habel, Ford, Edwards and Woods in professional learning communities and professional development groups. Their goals are to come to understand the effects of unintentional racism and stereotype threat on their students’ learning and to develop and implement classroom strategies to counter those effects. Cohen Steele, and Ross (1999) suggest that teachers can learn to provide “wise criticism” to their students in order to reinforce quality and guide their students to improve those aspects of the work that don’t yet meet the standard of excellence. However, in order to benefit from the feedback and use it gainfully, the students must hold three essential beliefs: that they belong or are welcome in the academic setting of the classroom, they are able to reach the standard of excellence, and their teachers are not influenced by a negative stereotype toward a group of which the students are members. Through “wise criticism” – words and actions – teachers can foster and maintain all of these beliefs.

Penny Lewis, the physical education teacher at Dickson, and Leslie Blaich, a teacher of first- and

To the Child with Wild Eyes

Your colors
Awaken me;
Hypnotize
Me
Back to a time when I didn’t know my ignorance.
A child – 7, 8, 25 years old –
Didn’t know the hatred behind
The N-word my grandma used.
There were no lessons
No history
No teachers teaching me
Of the past, the struggle, the future –
But this
Is about YOU and NOW –
And who am I to think I know how to teach you well?
YOU teach me what I would otherwise not know.
YOU are my inspiration to inspire.
And for that
I owe you
A chance
And an opportunity
To rise above
That place all my teachers told me you would reach.

Thank you child of many beautiful colors
for opening me to all the possibilities I never knew.

Blaich wrote this poem and read it to her fellow teachers at a faculty meeting in September.
second-graders at the school, participated in a four-day summer workshop run by Habel and Ford and serve as members of the professional learning community that consults with Habel and Ford. Lewis offers her view of the Courageous Conversations project:

The greatest impact of Courageous Conversations on me is how my eyes have been opened to my own aversive to racism. Having grown up in a liberal, open-minded household with parents who, by example, taught me not to judge people by skin color, I was absolutely convinced I did not have a racist bone in my body. I was completely shocked to come to the realization I had been trying so hard not to ever appear racist, I was making allowances and excuses for students just because of their skin color. I was prejudging and making assumptions that colored my thinking. I was offering undeserved praise and lowering expectations for these students in an effort, I believed, to build self-esteem. I did not realize this as a form of racism. My intentions were honorable but in fact these behaviors were detrimental to these students. WOW! Powerful stuff. ✨

**REFERENCES**


Reconnecting the Human Connection: A Cognitive Treatment of Language

LEIGH MORROW-ODOM
Speech Communications and Disorders

Although a researcher, I embrace the title of clinical aphasiologist, which means that I help people with an acquired language disorder called aphasia recover the language skills they have lost following a brain injury – typically a stroke. Many persons with aphasia have lost the ability to verbally express their wants and needs, to understand what others say to them, to read and write, and to retrieve the names of even the most common objects. It is not difficult to imagine the impact such a disorder would have on self-worth, family dynamics, vocation, and quality of life.

Not too long ago, I found myself in a unique position. Although I had hoped to earn the Ph.D. in speech-language pathology and open a private practice in my hometown, I was instead introduced to the relatively new world of brain imaging. Things change when you see your brain for the first time. You begin to appreciate its awesomeness as well as its
vulnerability. I finally gained a more humble appreciation of my patients’ struggles and of my purpose as a clinical aphasiologist. As a result, my research ideas began to take a different shape, and I finally realized the amazing opportunity I had been given to change the lives of so many who have lost the human connection: communication.

My new-and-improved goal was to develop better treatment approaches to improve the language abilities of my clients and, beyond that, to predict the optimal treatment for a client based on the location of damage in the brain. This line of research evolved from the data collected for my dissertation several years ago. The purpose of that study was to identify the parts of our brains we use to learn new words. To do this, participants underwent 32 minutes of functional Magnetic Resonance Imaging (fMRI) while completing an experimental novel-word learning task. Participants without a history of stroke learned eight novel words with nearly 100% accuracy, and their group fMRI scans revealed robust brain activity during the task (Figure 1). Interestingly, there was only one region of the brain that could predict learning in this group: the precuneus (Figure 2). The precuneus has been said to play a role in visuospatial imagery, episodic memory retrieval, and self-processing operations (Cavanna & Trimble, 2006). Quite possibly, participants utilized a learning or memory strategy related to the shape of targets to recognize and recall correct picture-word matches. It may be this strategy selection that led to the correlation between learning and precuneus activation.

This experiment was also run with persons with aphasia, and the results were markedly different. These participants were unable to learn any of the three novel-words presented to them and showed no consistent patterns of brain activity. This, of course, led to another handful of questions needing answers. Why were the persons with aphasia unable to learn new words? Is it the language impairment? What about the learning strategy? Did they have a strategy, and if they had it, did they implement it? And if they implemented that strategy and it failed, did they identify its inadequacy and try something else? My answers to these questions are that I don’t think it’s just the language impairment, and I don’t think they established a strategy.

Among others, we have shown that persons with aphasia often demonstrate a concomitant impairment of executive function (Fridriksson et al., 2006; Purdy, 2002). Our executive functions allow us to plan, organize, strategize, and monitor events in the world around us. It makes sense that our executive functions need to be intact in order for us to complete a task as complex as learning new words, but also for language processing in general. This issue of executive function impairment in persons with aphasia is where I began my independent research career at Western Carolina University.

Understanding executive-function impairment and its effect on language processing is crucial to designing improved assessment, restorative and compensatory rehabilitation, and discharge planning across disciplines. Further, it can improve patient and caregiver education and training to facilitate functional communication in activities of daily living, thus improving quality of life. Considering the long-term negative impact of executive function impairment on recovery, early identification is critical to optimize rehabilitative time and effort.

Although the presence of cognitive impairment in persons with aphasia has been a topic of debate for decades (Head, 1926; Goldstein, 1948; Wepman, 1972), recent advances in neuroimaging have made it possible to correlate these deficits with extent and location of brain damage using a technique called voxel-based lesion-symptom mapping (VLSM). Structural MRI scans can be used to identify a lesion location responsible for producing a particular behavior following injury.
by comparing lesion maps of a group with the behavior and a group without. To date, no studies have attempted to delineate regions of brain injury associated with executive function impairment in persons with aphasia using objective, parametric analyses. I believe an improved understanding of this relationship between lesion location and executive function impairment in aphasia will provide imperative prognostic information and improve aphasia treatment outcome.

Helm-Estabrooks (1998) suggested that successful aphasia treatment depends heavily on the relative sparing of the cognitive system. Nonetheless, the use of executive function treatment in aphasia has received little attention in the literature. It has been suggested that self-cueing improves naming abilities for some patients with aphasia, and that long-term retention of targets trained using self-cues was determined to be better than those trained without self-cues (Marshall et al., 1992; Robson et al., 1998). These studies suggest great potential in treating executive function in aphasia. My research will assess the effectiveness of a problem-solving treatment to improve executive function in aphasia.

This treatment approach will train persons with aphasia to develop a word-retrieval strategy for the purpose of self-cueing, to initiate that strategy spontaneously when the target is presented, and to monitor the effectiveness of that strategy. Training the development and use of strategies to improve naming should theoretically generalize better to untrained targets, improving functional communication. Showing that this treatment works for some of our patients would be a great contribution to the field, but it would be made even better if we could predict who would benefit most from receiving it. We can do this using the VLSM analysis technique. Using the structural MRI scans of participants completing the executive function treatment, it is possible to identify lesion locations predicting more successful and less successful treatment outcome.

Although much of this research leans heavily in the direction of neuroscience, it remains grounded in how we care for our patients. The ultimate goal is not to create colorful pictures of the brain to impress friends and family, but to improve the quality of life of someone who has lost something as simple and sacred as the ability to communicate. As healthcare professionals, we are motivated to help our patients achieve the most recovery possible, in what little time we have with them. It is my hope that this research will stay true to its clinical roots and change the lives of the people we care for.

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Performing and Teaching in Russia

P. BRADLEY ULRICHI
School of Music

Trumpet player and WCU Music Professor, P. Bradley Ulrich, recently returned from a trip to St. Petersburg and Moscow, Russia. Ulrich traveled to St. Petersburg to perform at the Oct. 1st Gala Concert of the 7th Annual International Romantic Trumpet Festival. The International Romantic Trumpet Festival consists of three or four concerts throughout the year that feature the trumpet as a solo instrument. Often these concerts showcase the trumpet with jazz band, orchestra, organ, piano, or brass ensembles. The October 1st Gala Concert took place in the beautiful Glinka Philharmonic Hall and featured classical trumpet concerti with orchestra accompaniment. P. Bradley Ulrich performed Neruda’s *Concerto in E-flat* and was joined on the program by two other American trumpet players who traveled with him, Eric Yates from the University of Alabama, and Grant Peters from Missouri State University. Each soloist performed with the Orchestra of the Russian National Library with Vasily Zvariiichuk, artistic director and conductor. Ulrich has become the United States Representative for the International Romantic
Trumpet Festival and this was his third trip to Russia. The first trip was in 2005 with the Smoky Mountain Brass Quintet, quintet in residence at WCU; the second time he performed as a soloist in 2008. Dr. Ulrich has helped bring numerous American trumpet players to Russia since 2005.

The day after the first solo performance, Dr. Ulrich gave a master class at the legendary St. Petersburg Conservatory (Rimsky-Korsakov). The Russian students at the conservatory were of a very high quality, displaying a remarkable level of musical maturity in their performances. The trumpet professors at the Conservatory are Boris Taburetkin, former principal trumpet of the Mariinsky Theatre Orchestra (formerly the Kirov Ballet) and Mikhail Romanov, assistant principal, third trumpet with the St. Petersburg Philharmonic (formerly the Leningrad Symphony Orchestra). Several Russian trumpet students spoke English very well and acted as translators throughout the two-hour clinic that featured three students who performed solos with piano accompaniment. Following critiques on their performances, the students were given the opportunity to ask questions of the American trumpet players. The Russian students and professors were very interested in the methods used by American trumpet teachers and how they structure individual lessons at the university level. American students have access to many pieces of music and method books of which the Russians are unaware. While all the students at the Rimsky-Korsakov Conservatory own top of the line instruments similar to the ones used at WCU, their solo repertoire is limited mostly to the music of Russia and France. Dr. Ulrich provided many of his own arrangements and some of his favorite American trumpet ensemble music to the teachers at the Conservatory to help broaden their repertoire. Ulrich also cautioned the students to keep their identity as Russian trumpet players alive. Most trumpet players around the world believe American trumpet players to be the highest quality and try to imitate their sounds and style. Because of the quantity of excellent recordings that are readily available, players around the world are beginning to sound the same and the beautiful Russian trumpet tradition is in jeopardy of dying away.

Following the clinic at the St. Petersburg Conservatory the Americans then travelled to Moscow to perform at the Moscow Conservatory (Tchaikovsky), where they met their host Vladislav Lavrik, principal trumpet of the Russian National Orchestra. On October 5th, Lavrik, who also teaches at the Conservatory, provided the guests an opportunity to work with many of Russia’s finest trumpet students. The players, who demonstrated fine technique and passionate musicality in their performances, responded well to suggestions concerning a number of technical topics popular in America. In addition to Lavrik, the Conservatory trumpet faculty includes Vadim Novikov, a legendary teacher in Russia. The Americans found that the language of music and trumpet are the same in any country and everyone has the same difficulty with the instrument! The Russian students have a passion to improve and are very interested in the way Americans teach and learn to play the instrument. Many questions were asked about breathing, articulations, and how to play better in tune. These are all areas that American trumpet players are considered experts.

The evening concert featured the American soloists, this time accompanied by pianist, Svetlana Orudjeva. Following the solo performances, the American performers were joined by Vlad Lavrik and four conservatory students who performed three trumpet ensemble works, including one of Brad Ulrich’s arrangements, What Sweeter Music, by John Rutter. Ulrich then presented one-year International Trumpet Guild memberships to each of the four student performers and Vlad Lavric. Because of his involvement with the membership committee of ITG, Ulrich was able to secure free memberships for the students. Most trumpet
players in Russia find it difficult to afford a yearly membership to ITG and they were extremely appreciative of this gift.

On their final evening in Moscow, Ulrich and the other American trumpet players were invited to present a master class at the Russian Military Music Academy in Moscow. This is a school where teenage musicians interested in careers in military bands live and study. All of the music students wore Russian army uniforms and were assembled for the clinic, with a student brass quintet greeting the Americans with a rendition of the jazz standard, *String of Pearls*. Following the student performance, the American trumpeters performed their solos for the students. Four trumpet students from the academy then played for the Americans, who offered comments on their performances in front of several hundred cadets. A question and answer session at the end of the clinic was stimulating for all, with students and teachers asking the guests for details regarding American teaching styles, studio activities, breathing, and other topics.

This trip to Russia was a highly enjoyable and very enlightening experience. The Russians are an incredibly warm, emotional people and were welcoming and polite at all times. The generous and receptive nature of the Russian music students, teachers, and audiences made every performance and clinic a pleasure. The artistic culture and musicianship evident in the trumpet activities at the famous conservatories in St. Petersburg and Moscow strengthened the Americans’ respect for the Russian trumpet playing tradition. Dr. Ulrich is currently working to bring students from the Moscow Conservatory to WCU to study music and interact with his students in the School of Music. He has been invited back to Russia again next year and will likely be taking some of America’s finest university teachers with him to share our musical culture.
Vector-borne Diseases: From Global to Local

Introduction

Vector-borne diseases are caused by infectious agents (e.g., viruses, bacteria, protozoa, and helminths) that are transmitted, or “vectored,” from an infected host to an uninfected host by an arthropod (e.g., mosquito, tick, etc.). As a whole, these diseases are responsible for enormous suffering and economic suppression and account for more than 25% of all emerging infectious disease events in the last decade (Jones et al. 2008). From a global perspective, malaria is the biggest vector-borne killer. Conservative calculations suggest that a person (typically a child or young mother) dies every 30 seconds from this disease (WHO, 2008). Other estimates suggest that nearly half of the global population is at risk of malaria and that up to 5 billion clinical episodes occur each year resulting in upwards of 3 million deaths (Breman et al. 2004).

Changes in public health policy and human behavior, coupled with insecticide/drug resistance and increased population movement, have resulted in the emergence or resurgence of vector-borne diseases throughout the world (Gubler 1998). Even in the United States, mosquito-borne diseases (e.g., West Nile, Saint Louis, La Crosse, and Eastern equine encephalitis) occur every year. Likewise, tick-borne diseases (e.g., Lyme, Rocky Mountain spotted fever, and human babesiosis) are increasingly recognized. Here in western North Carolina, one particular vector-
borne disease (La Crosse encephalitis), occurs every year and is responsible for the vast majority of human mosquito-borne disease in the state.

La Crosse Encephalitis: An emerging infectious disease in our backyard
Every summer, local children (typically less than 16 years old) end up in hospital intensive care units suffering from La Crosse encephalitis, a viral infection and inflammation of the brain. The cause of this insult: the bite of a mosquito infected with La Crosse virus. Death is rare from La Crosse virus (Case Fatality Rate <1%). However, the social and economic burden of the disease is high, especially when life-long disabilities result from the infection (Utz et al. 2003). Although cases of La Crosse encephalitis have been recognized in western North Carolina since 1964 (Kelsey and Smith, 1978), the annual number of recognized La Crosse encephalitis cases in western North Carolina appears to be increasing. However, these recognized cases only represent the “tip of the iceberg” in terms of virus transmission. For every one recognized case of La Crosse encephalitis, it is likely that more than 200 individuals were exposed to the virus through a mosquito bite but did not have any symptoms (Rust et al. 1999). Furthermore, a substantial number of clinically apparent La Crosse virus infections that occur each year in North Carolina are not diagnosed or recognized.

La Crosse virus is maintained in nature through vertical transmission between mosquito generations of the primary vector. When an infected female mosquito lays her eggs, some of the offspring will be infected with the virus through transovarial transmission. In addition, horizontal transmission within the same generation occurs through venereal infection and by a mosquito blood-feeding on virus-infected mammals. Sciurid rodents (i.e., squirrels and chipmunks) are the principle virus-amplifying hosts, but these vertebrates are only transiently infected for 3-4 days and do not serve as stable reservoirs of the virus (Watts et al. 1972; Ksiazek and Yuill, 1977). Human infections are incidental and do not contribute to virus maintenance or transmission.

La Crosse virus is transmitted to humans only through blood-feeding by an infected mosquito. The principle vector is *Aedes triseriatus*, the eastern tree-hole mosquito.

However, two invasive mosquitoes (*Aedes albopictus* and *Aedes japonicus*) are also capable of transmitting the virus to humans although their role in natural transmission remains unclear (Gerhardt et al. 2001; Sardelis et al. 2002). All three mosquito species are “container-inhabiting” in that they will lay their eggs in small containers holding water. These containers are generally classified as natural (e.g., tree-holes, rock pools, bamboo stumps, etc.) or artificial (e.g., abandoned tires, pots, buckets, etc.). Not surprisingly, neglected containers left near one’s place of residence will increase their risk of La Crosse virus infection.
In general, virus transmission is limited to woodland areas by the ecological requirements of both the mosquito and vertebrate hosts. Furthermore, the risk of La Crosse encephalitis in individuals is based on well described biological, behavioral, and environmental factors such as age, place of residence, nearby mosquito habitat characteristics, and time spent outdoors (Nasci et al. 2000; Erwin et al. 2002). Taken together, it is clear that the complexity of this disease system requires an interdisciplinary approach (e.g., biological, ecological/environmental, social, behavioral, etc.) in order to decrease transmission to humans (Moore 2008; Ellis and Wilcox 2009).

On-going Undergraduate Research at Western Carolina University

The ecology and epidemiology of La Crosse encephalitis in western North Carolina offers many opportunities for serious undergraduate research projects while simultaneously providing a service to citizens in our local communities. These projects are approached from the perspective of a collaborative investigative model where the student has shared ownership and responsibility. Examples of on-going undergraduate research projects are summarized below.

SPATIAL ANALYSIS OF LA CROSSE ENCEPHALITIS IN NORTH CAROLINA:

In collaboration with the North Carolina Division of Public Health and faculty from Western Carolina University’s Geosciences and Natural Resource Department, we are analyzing the spatial and temporal distribution of historical La Crosse encephalitis cases (1988-2009) in North Carolina using a Geographical Information System. Local indicators of spatial association will ultimately be used to identify hot spots of La Crosse encephalitis transmission and to measure clustering. These data will be used to further understand the local transmission dynamics of La Crosse virus in western North Carolina and to provide justification for future public health entomologic research and/ or interventions, including mosquito abatement.

OVITRAPping SURVEILLANCE OF CONTAINER-INHABITING Aedes Mosquitoes:

Since August 2008, students from Western Carolina University’s Environmental Health Sciences program have been involved in a project to identify what species of container-inhabiting Aedes mosquitoes are present in western North Carolina. The project involves the use of ovitraps at sites on and around campus in order to identify what species are present and their relative abundance. The eggs laid during oviposition are collected on strips of seed germination paper, counted, hatched and then morphologically identified to species. To date, more than 12,000 Aedes mosquitoes have been collected. Interestingly, the vast majority (>90%) of the mosquitoes collected to date are invasive to the region.

MORPHOLOGICAL STUDIES TO AID IN THE IDENTIFICATION OF DAMAGED ADULT MOSQUITOES:

Commonly used mosquito collection methods, such as CDC light traps, are often damaging to the adult specimens when they are captured. As a result, the morphological characters used in the current keys to mosquitoes are frequently destroyed by these methods. In this study, five Aedes species found in La Crosse virus endemic areas (i.e., Ae. triseriatus, Ae. albopictus, Ae. japonicus, Ae. atropalpus, and Ae. aegypti) were examined for useful secondary morphological characters to aid in identification. An exhaustive literature search and the examination of preserved specimens were used to create a data matrix to aid in the selection of novel, useful secondary characters. The utility of these characters are currently being investigated through the examination of field collected specimens and through controlled trials in the laboratory using
common collection methods and laboratory reared specimens. The results from this project should immediately benefit environmental health professionals in La Crosse virus endemic areas who are responsible for the collection, identification, and processing of mosquitoes.

Molecular Methods to Identify Mosquitoes:
We are investigating the utility of molecular methods, specifically the polymerase chain reaction, to aid in the identification mosquitoes, including vectors of La Crosse virus. A molecular assay that rapidly and simultaneously identifies *Aedes* vectors found in LACV endemic areas is currently being validated.

Future Directions
The burden of La Crosse encephalitis remains poorly defined. Furthermore, the epidemiological importance of invasive mosquito species capable of transmitting La Crosse virus is unresolved. The latter is being addressed through on-going studies in collaboration with colleagues from the University of Florida and the Virginia Polytechnic Institute and State University. However, although there are a multitude of potential research opportunities, we are ultimately interested in decreasing the burden of La Crosse encephalitis disease. In that regard, the most effective way to reduce La Crosse virus transmission is to lower the number of artificial habitats (e.g., containers) in the environment. To do this will require community engagement with effective and sustainable educational programs. This will certainly require a true “interdisciplinary” approach across multiple disciplines and agencies.

References


Metamaterial Slow/Fast Light Structures Fabricated Using Rapid Prototyping Technologies
Abstract
Metamaterials, which are artificially engineered electromagnetic materials with properties and functions not readily available in nature, promise a wide range of applications from multi-functional environment sensing and monitoring, efficient green energy, health care and drug discovery, invisibility cloak and stealth technology, to wireless and optical communications. Kimmel School at Western Carolina University has in-house metamaterial fabrication and testing capabilities through its state-funded Center for Rapid Product Realization. Here we report a realization of metamaterial structures where the speed of light can be tunable from extremely slow \((c/30)\) to faster than the speed of light in vacuum. These novel structures have important applications in optical data processing as well as opportunities to advance fundamental understandings of nature.

I. Introduction
Metamaterials in a broader sense are artificially engineered electromagnetic materials that possess unusual properties not readily available in nature such as negative index of refraction. Referring to Figure 1, electromagnetic materials can be categorized by its responses to the electro-magnetic fields. The response to the electric field is characterized by the permittivity \(\varepsilon\); while the response to the magnetic field is characterized by the permeability \(m\). Propagating electromagnetic waves only exist in the media where the product of permittivity and permeability is positive, i.e., \(\varepsilon m > 0\). On the other hand, in the media where this product is negative, i.e., \(\varepsilon m < 0\), the electromagnetic waves cannot sustain. Instead, the electromagnetic fields decay exponentially away from the source, forming plasmonic modes called plasmons. The permittivity \(\varepsilon\) can assume both positive and negative values. For example, metallic materials typically have negative permittivity while dielectric materials typically have positive permittivity. However, all naturally occurring materials have been found with positive permeability or \(m > 0\). Furthermore, all naturally occurring materials found so far with \(\varepsilon m > 0\) have \(\varepsilon \geq 1\) and \(m \geq 1\), as noted in Figure 1. The index of refraction \(n\) relates to the permittivity and the permeability of the media by \(n^2 = \varepsilon m\). Normally all media assume positive index of refraction. Positive index of refraction ensures that, when an electromagnetic beam goes into the medium from air, the incident beam and the refracted beam are on the opposite sides of the normal to the interface as seen in Figure 2a. Veselago first postulated in 1960s that negative index of refraction can exist for the media where \(\varepsilon m > 0\) but individually \(\varepsilon < 0\) and \(m < 0\). Negative index of refraction will result in the negative refraction, where the incident beam and the refracted beam will be on the same side of the normal (Figure 2b). This claim did not attract much research activities until more recently in 2000 Sir Pendry [1] further postulated that a slab of negative index materials (NIM) can amplify all evanescent waves and is therefore capable of perfect imaging. Pendry’s theoretical result, while still remains controversial up to today [2-6], has inspired exponential growth in research activities in NIM and in general metamaterials [7-10]. Employing metamaterials, it has been proposed that, many unprecedented applications are possible, including super-resolution imaging [12-17], quantum levitation [18], optical black hole [19-22], and invisibility cloak [23-30]. Some of these exciting applications including invisibility cloak have been demonstrated to various degrees of success. In this paper we will discuss basic structures of metamaterials and their fabrication. In particular, we will discuss the capability of the current state-of-the-art rapid prototyping technologies from 3-D printing to laser micromachining and their applications to metamaterial fabrications. We will also present both theoretical and experimental results of metamaterial structures that are capable of tunable group index from extremely slow \((c/30)\) to faster than the speed of light in vacuum. These novel structures have important applications in optical data processing as well as pose intriguing challenges to fundamental understandings of nature.

In the sections below, we will discuss the basic structures of metamaterials, the resulting novel electromagnetic properties and their possible applications in Section II. Next, in Section III, we will introduce the current state-of-the-art in rapid prototyping technologies in comparison to the
conventional fabrication process of metamaterials. And then, in Section IV, we present our in-house fabricated metamaterial fast/slow light structures with both the theoretical principle and experimental measurement results. The conclusions with an outlook of future research into THz and optical metamaterials with rapid prototyping fabrication technologies are presented in Section V.

II. Metamaterials and Metamaterial Applications

Similar to naturally occurring materials, metamaterials have also their “molecular” and “crystal” structures. As shown in Figure 3, the “molecular” structure of a metamaterial is the structure of the unit cell that repeats itself. The repetition pattern is the “crystal” structure of a metamaterial. Metamaterials gain the unusual electromagnetic properties through both the “molecular” and the “crystal” structures. Unlike naturally occurring materials, however, metamaterial “molecules” consist of engineered patterns of metal or other materials typically having strong responses to electromagnetic fields. Figure 3a shows examples of metamaterial “molecules” of different metallic micro structures. Figure 3b shows a rectangular repetition pattern that forms one kind of a metamaterial “crystal” structure. A famous metamaterial structure is shown in Figure 4. It consists of “split-rings” as shown in Figure 3a on one side of an insulating layer and an array of parallel conducting strips on the other side. It is one of the earliest metamaterial structures proposed and realized [31-34]. The parallel conducting strips are inductive. However, an inductor can also be considered to be a negative capacitance, which produces effective negative electric permittivity. The open splitting resonators, on the other hand, give rise to a resonant circulating current, which in turn is able to produce a negative magnetic permeability. In combination, the split-ring structure provides effective negative permittivity and permeability simultaneously for a specific frequency range, producing effective negative index materials (NIM). These structures can be accurately modeled with RF/microwave CAD tools that have been developed over decades for RF/microelectronics circuits and applications. NIM has been predicted to have properties that can make perfect imaging possible [1]. However, The biggest hurdle is that the predicated perfect imaging scheme by NIM slabs is very sensitive to the loss, which tends to

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FIG. 2: (A) Refraction between normal materials. (B) Refraction between normal material and negative index material.

FIG. 3: (A) Example metamaterial “molecular” or unit cell patterns; (B) A simple metamaterial “crystal” structure or repetition pattern.

FIG. 4: Metamaterial structure used to demonstrate the doubly negative material, i.e., negative index material and negative refraction. (After Ref.[6])
limit the scheme, only work partially in the near field of a fraction of wavelength [35,36].

The electromagnetic properties of metamaterials are determined by the engineered metamaterial “molecules,” as well as how they are arranged spatially, which is the “crystal” structure of the metamaterial. The periodicity is typically on the same order of or less than the wavelength of the electromagnetic waves, which ensures the higher orders of diffraction are minimized. The “crystal” structure, or the orderly fashioned periodic patterns, typically gives rise to anisotropy similar to that of crystal optics. A simplest example can be a pattern of “lines and spaces” as shown in Figure 5, where the thickness of the lines as well as the spacing between them are smaller compared to the wavelength. This structure has long been known as the form-birefringent structure where the indices of refraction for the polarizations parallel and perpendicular to the lines can be very different [37,38]. While naturally occurring crystals have similar birefringent properties, the index difference between the two different polarizations is usually quite small. Accordingly, in order to acquire a substantial phase difference between two polarizations, the birefringent layer has to be many orders of magnitude of wavelength in thickness. In contrast, for form-birefringent structures, larger phase difference between the two different polarizations can be obtained in the thickness of only a fraction of wavelength. The periodic “crystal” structure of metamaterials also strongly modulates the dispersion relation of the media. It can result in super-prism effects and sees a wide range of applications in polarimetric sensors, optical signal processing and compact optical networking devices. The spatial pattern of metamaterial “molecules” also plays an important role in transformational optics where the index of refraction smoothly varies with the spatial coordinates. This capability has been demonstrated to be critical for the novel applications such as conformal shaped antenna, solar energy concentrators, as well as the invisibility cloak [23-30].

Similar to their naturally occurring condensed matters such as glasses, metamaterial structures can also be amorphous, where there is no long-range order of the “molecules” can be identified. These amorphous metamaterials will gain their unusual properties mainly from the “molecular” structure and tend to be polarization independent. Usually in such cases, the metamaterial “molecules” have strongly enhanced electromagnetic responses, such as for plasmons. In general, plasmons are implemented as metal particles with the feature sizes that are of the wavelength scale. For visible range of electromagnetic spectrum, they are typically nanometer-sized metal particles. As a matter of fact, this is how various metallic paints obtain their different colors and hues. The strongly enhanced electromagnetic responses of metamaterial plasmonic “molecules” are naturally more sensitive to its environment. In particular, when certain large biochemical molecules or function groups are close by or affiliated with the metamaterial “molecules,” the electromagnetic responses of the metamaterial can be significantly modulated, providing sensitive means of detecting and labeling such biochemical molecules or function groups. This process is similar to the current biochemical testing scheme called surface plasmon resonance (SPR) enhanced Raman spectroscopy, where the proximity of certain biochemical agents, such as Anthrax, pore to the surface plasmon, significantly modulates the coupling of laser light and gives the enhanced sensitivity to the Raman spectroscopy, identifying tiny trace amount of the biochemical agents in question. This sensitive detection and labeling capability will cast a light on many important applications in biochemical sensing as well as help drug discovery process to be more

<table>
<thead>
<tr>
<th>METAMATERIALS</th>
<th>POTENTIAL APPLICATIONS</th>
</tr>
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<tbody>
<tr>
<td>NIM/Indefinite media</td>
<td>Perfect imaging; super-resolution imaging, hyper-lenses</td>
</tr>
<tr>
<td>Zero index materials</td>
<td>Invisibility cloak; field enhancement</td>
</tr>
<tr>
<td>Plasmonic materials</td>
<td>Biochemical sensors, compact optical devices</td>
</tr>
<tr>
<td>Form-birefringent materials</td>
<td>Polarimetric sensors, field concentrators, effective NIM/Indefinite media, super-resolution imaging</td>
</tr>
</tbody>
</table>

**FIG. 5:** Form-birefringent disk patterned with interleaving lines and spaces.
The table above summarizes the novel electromagnetic properties of metamaterials and their potential applications.

III. Rapid Prototyping Technologies for Metamaterial Fabrication

Rapid prototyping (RP) in a general sense refers to an automated process whereby digital 3D patterns and structures created using computer aided design (CAD) software are built by either an additive or a subtractive process. For additive processes, the digital models are “sliced” into horizontal layers and then built, layer by layer, by adding material. Typically these processes begin at the bottom of the build envelope and work upwards. These processes include stereolithography (SLA), selective-laser-sintering (SLS), fused deposition modeling (FDM), PolyJet, electron beam melting (EBM), and 3D printing. SLA uses an ultraviolet (UV) laser to cure a photo resin placed into a vat that solidifies when exposed to ultraviolet light. After the laser beam scans across each cross-section, the build platform moves down, exposing uncured liquid resin for the next layer. This process repeats until the part is complete. A wide variety of available resins mimic the properties and aesthetics of polymers – such as polypropylene, ABS, and polycarbonate. SLS is a process similar to SLA, however instead of using photo resins, the system uses a CO₂ laser to heat and bind each layer of a tightly compacted powder. Available materials range from durable plastics and elastomers, to aluminium and titanium alloys. FDM, on the other hand, is an extrusion process in which a thermoplastic monofilament travels through a heated tip, and follows software-created toolpaths to form each layer, as a build platform moves down to prepare for building the next layer. This technology uses actual engineering polymers such as acrylonitrile butadiene styrene (ABS), polycarbonate (PC), a PC/ABS blend, polyphenylsulfone (PPSF), and Ultem 9085™. The PolyJet process uses photo resins as in SLA, but uses print heads with small valves that deposit tiny droplets of resin that are subsequently cured by high intensity UV lamps. Materials range from elastomeric resins to materials with polypropylene and ABS-like physical properties. This technology also allows for the creation of composite materials and for fabrication of multi-material parts (such as parts with rubber over-molding). EBM is similar to sintering, but instead of using a laser to solidify each layer, an electron beam is used. In addition, the build envelope is heated, and under vacuum. Available materials include titanium and cobalt-chrome alloys. 3D printing is often used to describe any desktop or office rapid prototyping technology, however in this text the term will be limited to machines that make parts from a powder. For this process, an inkjet print head moves back and forth across a bed of powder, depositing a liquid binding solution that solidifies each layer. Materials include composites, elastomers, and casting materials used for both direct-metal and investment casting. Figure 6 shows a 1D form-birefringent metamaterial where the unit cell is fabricated using FDM process. Such structures can dramatically slow down the electromagnetic waves and enhance the signal strength efficiently.

The subtractive process, on the other hand, is more similar to traditional milling machining processes where one starts with a bulk material and the models are built by taking away material. There are six main categories of processes used in laser micro-machining. Single shot drilling refers to drilling through with a single laser pulse. Percussion drilling refers to drilling through using a series of laser pulses. Trepan drilling, sometimes also called helical drilling, refers to drilling using a series of laser pulses and moving either the beam or part in a circular path. Cutting refers to cutting through using a series of laser pulses and moving either the part or the laser beam, sometimes in a single pass, but often multiple passes are used. Etching/milling is a process that removes material to a defined depth by controlling the laser pulse energy and number of pulses per location. Marking process changes the surface appearance either by material removal or color changes by, for example,
oxidization. For these laser machining processes, the laser beam is focused in order to concentrate the power to a level that is capable of removing or changing material. The minimum feature size is proportional to the size of the focused laser beam. Due to diffraction, the smaller the focused spot size, the larger divergence of the laser beam. Accordingly, the uniform drilling thickness also varies. The larger the focused spot size, the longer the uniform drilling, and vice versa. Often an aperture or iris is put in the beam path before the lens. This is often used to reduce the laser power or improve the beam shape. The size of a percussion-drilled hole is usually larger than the actual spot size. Also the entry hole can be 2 – 3 times the beam size owing to a combination of factors such as threshold effects, plasma and thermal effects. The size of the machined feature only approaches that of the actual laser spot when the pulse energy is low and/or when velocity of the beam relative to the workpiece (when cutting or trepanning) is relatively high. On the other hand, single shot drilling, while may not drill through the sample, can nonetheless be optimized for fine feature sizes that can be the same or even smaller than the focused spot size. This can be used for micro-milling, which is a process of controlled depth removal. Here the laser beam is passed over the surface and ablates a trough whose width is approximately the spot size; and the depth depends upon the material, laser pulse energy and feedrate. Since different materials response to the laser beams differently, in general it is necessary to iterate most of the laser machining parameters several times in order to get the best result tuned to a particular process and host material.

Advancement in both additive and subtractive methods and, in particular, in the precision laser micromachining has opened a new possibility for rapid prototyping and manufacturing 3D patterns and structures that can exhibit unusual optical properties, i.e., optical metamaterials. Table 2 summarizes for the rapid prototyping technologies described here: typical feature size, the maximum build envelope, and potential applications in metamaterial structure fabrication.

As can be seen from the above table, advanced RP processes provide a wide range of choices for fabricating 3D patterns and structures, covering virtually all frequency ranges of metamaterials from microwave to optical frequencies. Traditional metamaterial fabrication, for example, for optical frequencies typically employs sophisticated semiconductor lithography technologies involving multiple steps of processes under high vacuum and clean room operations. Laser micro-machining, in particular, provides a promising cost-effective alternative for optical metamaterial fabrication.

At WCU’s Center for Rapid Product Realization, we use both additive and subtractive prototyping technologies for the purpose (but not limited to) of creating metamaterials structures. The center houses a Stratasys® Fused Deposition Modeling (FDM) machine that can create parts using common engineering plastics, such as ABS, Polycarbonate, and Polyphenolsulfone. As described before, this is an extrusion process whereby a polymer monofilament is extruded through a heated tip (typically .016” I.D.) and then depositioned in .010” thick layers to build up a physical prototype. This process has been used extensively to create not only test structures, but fixtures and mounting hardware as well. The center also employs two other additive prototyping technologies: a 3Corp 400 3D printer, and an Objet Eden333 UV Polyjet machine. The 3Corp system

<table>
<thead>
<tr>
<th>RP PROCESS</th>
<th>MINIMUM FEATURE SIZE (mm)</th>
<th>BUILD ENVELOPE (cm)</th>
<th>METAMATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLA</td>
<td>50</td>
<td>150x/75y/55z</td>
<td>THz, RF, Microwave</td>
</tr>
<tr>
<td>SLS</td>
<td>80</td>
<td>55x/55y/75z</td>
<td>THz, RF, Microwave</td>
</tr>
<tr>
<td>FDM</td>
<td>127</td>
<td>91x/61y/91z</td>
<td>RF, Microwave</td>
</tr>
<tr>
<td>PolyJet</td>
<td>16</td>
<td>50x/40y/20z</td>
<td>THz, RF, Microwave</td>
</tr>
<tr>
<td>EBM</td>
<td>50</td>
<td>20x/20y/30z</td>
<td>THz, RF, Microwave</td>
</tr>
<tr>
<td>3D Printing</td>
<td>90</td>
<td>25x/38y/20z</td>
<td>THz, RF, Microwave</td>
</tr>
<tr>
<td>Laser Micro-machining</td>
<td>&lt; 1um</td>
<td>10x/10y/10z</td>
<td>Near IR Optics</td>
</tr>
</tbody>
</table>

*TABLE 2: Typical feature size and the maximum build envelope of different RP technologies.*

*FIG. 7: Laser micro-milled hole 50 mm in diameter.*
builds up parts in layers using a fine powder and an adhesive binding solution, while the Objet polyjet machine uses thin layers (.0006” thick) of acrylic photopolymers to create prototypes. In addition to additive prototyping, the center also has subtractive prototyping capabilities through the use of a Haas CNC (Computer Numeric Control) machining laboratory. Aside from conventional milling technologies, the center also has laser machining systems used for laser cutting and ablation. These systems include a Haas Z4-500 watt CO₂ laser, and an Oxford Lasers DP100-5S solid state, diode dumped (Yttrium Vanadate) laser micro-machining system. The Oxford Lasers machine is a dual-wavelength system offering both 266 nm and 532 nm beam lines, and is shown in Figure 8. Such a broad range of fabrication technologies allows the Center for Rapid Product Realization to work with an extensive range of polymers, metals, and composite materials, and ideally suitable for alternative fabrication process of metamaterial structure from microwave to optical frequencies.

IV. Metamaterial Fast/Slow Light Structures

Fast/Slow light structures are useful in optical data storage and processing applications. Slow light structures are also the candidates for field concentrators, since as the speed of light is slowed down, the energy density of the field increases proportionally – providing the material loss is small. Furthermore, in fast light structures, the group velocity of electromagnetic waves can be negative, representing a transmission of light pulse peaks at a speed that is faster than the speed of light in vacuum [50-54]. This superluminal propagation phenomenon, however, does not violate the principle of causality nor is it in contradiction to Einstein’s stipulation that no information can be transmitted faster than the speed of light in vacuum. This is because, for the group velocity to be negative, the media must be either in deep absorption or with large gain. In such strongly dispersive media, the information speed does not equal to the group velocity. Only in transparent regions of the spectrum where loss or gain can be ignored, the group velocity equals the energy velocity, at which the information can transmit. Negative group velocity, however, can be considered as effective negative index of refraction, which may have useful imaging and signal processing applications [55-57]. This effective negative index of refraction is evident in the cartoon shown in Figure 9. Given the index of refraction n and the speed of light in vacuum c, the accumulated phase after passing through a sample of thickness d is also a function of frequency w, φ(w)=nwd/c. The slope of this frequency dependent phase is directly related to the group delay by virtue of inverse Fourier transform. In Figure 9a, for example, the negative group velocity by definition occurs in the region where anomalous phase behavior occurs. Normally, for the frequency dependent phase as plotted in the figure, the negative slope corresponds to a positive group delay. Meanwhile, anomalous phase behavior occurs when the slope in the figure is positive. A positive slope here corresponds to a negative group delay. For the frequency dependent phase shown in Figure 9a, anomalous phase behavior occurs in the frequency range from w₁ to w₂. However, as shown in Figure 9b, the same accumulated phase φ(d)≡nwd/c can also be plotted vs. the thickness of the sample for a fixed frequency at the center of the anomalous phase behavior. Accordingly, there exists a range of the sample thickness, for example, from d₁ to d₂, during which the accumulated phase decreases with the increasing sample thickness d. This is the characteristic behavior of NIM. Fast/Slow light phenomena have been observed in many optical systems with strong dispersion [50-54]. Metamaterials, due to their unique capabilities of manipulating light transmission, can make compact tunable fast/slow light structures. In particular, Mandatori, et al. first predicated in theory a layered structure with anisotropic layers. This structure can exhibit the anomalous phase that gives rise to negative group velocity and effective negative index of refraction [55,56]. The simplest Mandatori structure can involve only a single layer of birefringent material and can be reduced to a birefringent filter model, where a piece of anisotropic medium is sandwiched between two parallel polarizers as shown in Figure 10. The realization that this familiar structure can provide a negative group delay and therefore effective negative index of refraction is a little surprising. However, as we will show later, naturally occurring birefringent media usually suffer a low index contrast Dn/n, which renders the predicted anomalous phase

FIG. 8: Oxford Laser DP100-5s laser micro-machining system.
behavior barely noticeable or useful. By using metamaterial structures, we have achieved very large birefringence, making compact Mandatori structures viable.

Given the birefringent index of refraction $n_x, n_y$ ($n_x > n_y$), the thickness $d$ of the birefringent layer and the field splitting ratio $a=|E_x|/|E_y| = \cotan2q$, which is determined by the azimuth angle $q$ between the lines of form-birefringent layer and the polarizers, the center frequencies of anomalous phase regions are found to be,

$$\nu_n = \frac{mc}{2d\Delta n}$$  \hspace{1cm} (1)

where $m=1,3,5,...$ is a positive odd integer, $c$ is the speed of light in vacuum, and $\Delta n = n_x - n_y$ is the index difference. The group index of refraction at the center frequency is,

$$n_g = n_y \left(1 - \frac{\alpha}{1 - \alpha \frac{\Delta n}{n_y}}\right)$$  \hspace{1cm} (2)

the bandwidth of the anomalous phase behavior is,

$$\Delta \omega = \omega_2 - \omega_1 = \frac{2c \arccos \alpha}{d\Delta n}$$  \hspace{1cm} (3)

and for $a<1$, the transmission throughput is

$$T = (1-a)^2$$  \hspace{1cm} (4)

From Eq.(2), in order for the group index to be negative, $a$ has to be smaller than 1. This is in agreement with the condition given by Mandatori, et al. [55], that the field component with the larger index of refraction has to have the smaller amplitude. For naturally birefringent materials, the index contrast, $\Delta n/n_y$ is typically less than 1%. Accordingly using naturally occurring birefringent materials, the group index is negative only if $0.99 < a < 1$. This would result in a transmission throughput of $9.8\times10^{-5}$, or an insertion loss of more than 40 dB, which has little practical interest. However, for a large birefringence of, for example, $\Delta n/n_y = 1$, the group index can be negative for $a$ as small as 0.5, resulting in a transmission throughput of more than 25%, or a 6 dB insertion loss, which is acceptable for
many applications.

For the simplest structural pattern that induces form birefringence known as a sub-wavelength period grating, i.e., an array of parallel lines separated by air as shown in Figure 5, the maximum index contrast occurs when the filling ratio is 0.5 and,

\[
\frac{\Delta n}{n_{\text{min}}} = \frac{1}{2} \left( \frac{n+1}{n} \right) - 1
\]

(5)

For a moderate host material index of refraction of \(n=1.6\), which corresponds to the low cost ABS plastics in X-band (8GHz – 12 GHz), the maximum index contrast can be more than 0.11. Figure 11a shows an ABS form-birefringent disc designed for X-band operation. The lines and spacings are each 500 mm. The discs are fabricated by using the Stratasys FDM Titan rapid prototyping machine. Injection molding process can be used for large volume production at low cost of these high index contrast birefringent structures. Figure 11b shows a measurement of TE and TM refractive indices of the ABS form-birefringent disc from the complex transmission spectrum of a 5mm thick sample. The large variation of index of refraction below 9 GHz is attributed to the X-band waveguide dispersion and a weak multi-path interference due to the difference between the indices of refraction of the disc and air. At 10 GHz, the index difference \(D_n\) is 0.14, yielding an index contrast of 0.11, which is in excellent agreement with the predication by birefringence mixing formula. The index contrast can be further increased by surface treatment of the form-birefringent discs using a metallic paint. Figure 12 shows the measurement of the surface-treated ABS form-birefringent disc. Index contrasts as high as 0.7 have been easily and reproducibly achieved. The increased dispersion for the surface-treated form-birefringent discs is due to the increased absorption introduced during the process.

The experimental setup for measuring the negative group index of the Mandatori structure is shown in Figure 13. A vector network analyzer (VNA, Agilent Technology N5230A) is configured with an X-band free space architecture. The complex transmission spectrum \(S_{21}\) is used to calculate the group index. The X-band horn antennas are linearly polarized. The birefringent layer is rotated in respect to the horn antennas to form the azimuth angle \(q\) that determines the electrical field splitting ratio \(a = \cotan2q\) for single layer birefringent structures. The measurement of the azimuth angle \(q\) is from the...
displacement of markers on the edge of the circular birefringent disc with respect to the incident polarization orientation and has an estimated error of ±3 degrees. A through-calibration was performed with no DUT (device under test) in between the horns and used as the reference. Figure 14 shows the anomalous phase behavior in the calibrated transmission spectrum of the single-layer structure. Different traces correspond to different thicknesses of the form-birefringent layer. The azimuth angle is adjusted to be close to and slightly larger than 45 degrees, which according to Eq.(2.2) gives rise to the most significant anomalous spectral phase behavior as seen in Figure 14. The index difference $D_n$ can be estimated from these curves by identifying the center frequency of the anomalous phase and by using Eq.(1). The results are summarized in Table 3.

This is in excellent agreement with the direct measurement of the frequency dependent index and index difference for a number of different values of $D_n$, thereby validating the basis of the anomalous phase phenomenon. Figure 15a shows the spectral phase of the calibrated transmission spectrum for a 9 cm thick ABS form-birefringent layer. Different traces in Figure 15a correspond to different azimuth angles $q$, which determine different splitting ratios $a$. Around 45 degrees where the splitting ratio $a$ is close to 1, the slope of the spectral phase changes sign as predicted. According to the theory and Eq.(2), when $q$ is less than 45 degrees, $a$ is larger than 1 and the slope of the spectral phase is always negative, corresponding to a positive group index. When $q$ is close to but larger than 45 degrees, more energy is distributed to the slow axis (larger index of refraction) of the birefringent layer and $a$ is close to but smaller than 1. According to Eq.(2), the slope of the spectral phase will change sign and give rise to negative group index. The experimental results agree very well with these predictions for both untreated and treated ABS structures. A phase change close to 0.75p is observed for $q = 50$ degrees within a frequency band from 10.8 GHz to 11.4 GHz, corresponding to a calibrated negative group delay of 0.63 ns. Since the transmission is calibrated to air and it takes 0.3 ns for the RF wave to transmit through a 9 cm distance in air, this means an absolute negative group delay of 0.33 ns has been experimentally observed directly in the frequency domain. Accordingly, the corresponding measured group index is $n_g = -1.1$. Figure 15b shows the intensity responses and, as expected, the throughput $T$ is a function of the splitting ratio which changes appreciably with the azimuth

<table>
<thead>
<tr>
<th>THICKNESS (cm)</th>
<th>CENTER FREQ.(GHz)</th>
<th>$D_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>11.25</td>
<td>0.148</td>
</tr>
<tr>
<td>9.5</td>
<td>10.8</td>
<td>0.146</td>
</tr>
<tr>
<td>10</td>
<td>10.5</td>
<td>0.143</td>
</tr>
<tr>
<td>10.5</td>
<td>10.2</td>
<td>0.140</td>
</tr>
<tr>
<td>11</td>
<td>9.75</td>
<td>0.140</td>
</tr>
</tbody>
</table>

FIG. 15: (A) Frequency-dependent phase for a fixed thickness of 9 cm at different azimuth angles. (B) The corresponding frequency domain intensity response.

FIG. 16: Strong slow light behavior in surface-treated form-birefringent discs.
angle. For moderate fast light effects, obtained for example with \(q=80\) degrees, an 8 dB insertion loss is incurred, which is still acceptable.

The form-birefringent structures give rise to not only fast light phenomena but also slow light phenomena as evident in Figure 15a. For \(q < 45\) degrees, the group index of refraction will not turn negative. However, it can now be significantly larger than 1, exhibiting a strong slow light effect. This is most significantly shown in Figure 16, where the spectral phase of the transmission spectrum for surface-treated ABS form-birefringent discs is plotted. Different traces again correspond to different azimuth angles and the fixed birefringent layer thickness of 2.5 cm. The surface-treated ABS form-birefringent discs had an index contrast of 0.7. Owing to the increased index contrast, the total thickness of the birefringent layer for an operation center frequency around 10 GHz is only 2.5 cm. For the azimuth angle of 40 degrees, the accumulated spectral phase changes from -2.5 radians at 9.9 GHz to -7 radians at 10.2 GHz, corresponding to a calibrated delay of 2.4 ns and a slow light group index of \(n_g = 29.6\).

As typical for passive slow light media, a strong insertion loss of 25 dB is associated with this large slow light delay.

V. Conclusions and Future Outlook

In summary, we report here a realization of metamaterials structures where the speed of light can be tunable from extremely slow \((c/30)\) to faster than the speed of light in vacuum. We experimentally verified the anomalous phase in single-layer as well as multi-layer birefringent structures as predicted by Mandatori, et al.[55]. Large \(Dn/n\) of 0.7 has been realized in surface-treated ABS form-birefringent discs. This large birefringence is not readily available in naturally occurring media but is critical to make compact structures viable and useful. The design formula for single-layer structures for group delay and group index control are given here and verified by our experiments. With the availability of tunable negative group indices, these simple structures can play important roles in both practical applications and in the understanding and exploitation of fast/slow light phenomena. These metamaterial structures are fabricated by using current RP processes. With further development and advances in RP technology, in particular the laser micro-machining technology, RP presents a golden opportunity for cost-effective and high performance alternative for 3D optical metamaterial fabrication.

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REFERENCES
