



Fundamentals of logic, reasoning, and argumentation: an evidence-supported curriculum targeting scientific literacy to increase public understanding and engagement in science

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Abstract

The purpose of this article is to present an evidence-supported curriculum covering the fundamentals of logic, reasoning, and argumentation skills to address the emphasized basic knowledge, skills, and abilities required to be scientifically literate, which will prepare the public to understand and engage with science meaningfully. An analytic-synthetic approach toward understanding the notion of public is taken using a theoretical biomimetics framework that identifies naturally occurring objects or phenomena that descriptively captures the essence of a construct to facilitate creative problem-solving. In the present case, the problem being solved is how to reconcile what is meant by public, how it ought to be interpreted, determining the diverse levels of confidence in science that exist, and various understandings of science all with one another. The results demonstrate there is an inherent denotative-connotative inconsistency in the traditional notion of public that can be explicated through the concept of a fractal allowing for comprehension of the relationship between public confidence in, and understanding of, science.

Keywords: Curriculum; scientific literacy; science and the public; public understanding of science (PUS); public engagement with science (PES)



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1. Introduction

In a report by the American Academy of Arts and Sciences entitled “Perceptions of Science in America” (AAAS, 2018), it was suggested that additional research needs to be conducted, and it should expand upon the definition of science literacy in a manner that emphasizes the importance of understanding the scientific process and the ability to evaluate conflicting scientific evidence. Conflicting scientific evidence abounds, and there exists a plethora of examples in the media of both faulty reasoning and unfounded claims (Diethelm, 2009).

Despite all of the deficiencies in the Public Understanding of Science (PUS) on display in the media, the nature of the attitudes of the public toward science tends to be positive (AAAS, 2018). Also, for example, research has demonstrated that although various levels of confidence in science do exist, the majority of people believe that the benefits of science outweigh any potential risks (AAAS, 2018). Moreover, the public thinks the highest priority for science should be given to improving educational outcomes, reducing poverty, and finding cures for disease and illness (AAAS, 2018).

As admirable as the hopes for, and belief in, science may be, it is vital to understand that the publics’ trust or confidence is a function of demographics and the particular issue in question (AAAS, 2018). In fact, not only are members of the public found to have diverse levels of confidence in science but if asked to explain their understanding of the term “science,” one would discover that science means something different to each member (AAAS, 2018). That there exists no consensus concerning the public understanding of science as an enterprise should not astonish the reader because the state in which we find ourselves is a logical consequence of the notion of a public that I argue may be responsible for the issues that everyone, including students, ultimately has to face. These issues may be more readily appreciated by providing a potential framework for understanding with which we begin.



2. Theoretical Biomimetics as a Framework for Understanding: A Fractal Public

Whether constructing a skyscraper or building an airplane, humankind's most significant source of inspiration has been nature and it will always be its ultimate guide. Similar to the manner in which the principles found in natural things, or those underlying naturally occurring phenomena, are used to drive the development of human-made tangibles such as tall buildings or planes, Carroll (Carroll, 2017) has developed an approach to creating intangibles such as solutions in problem-solving, which compares and contrasts principles or phenomena as they exist naturally with real-world problems to gain insight and is referred to as Theoretical Biomimetics (TB). As a tool for analyzing the present issue of understanding what is meant by "public," applying theoretical biomimetics as a framework for recognizing in which way the problem or issue resembles objects or phenomena that are found around us in nature has been incredibly enlightening. Through the TB lens, we discuss what a public is, attempt to reconcile it with public confidence in science, and lastly consider the role that public understanding of science plays.

The dictionary defines "public" as people or community (Stevenson, 2011). Additionally, synonyms for the word public according to the same source include "citizens, subjects, the general public, electors, electorate, voters, taxpayers, ratepayers, residents, inhabitants, citizenry, population, populace, society, country, nation, and the world" (Stevenson, 2011). If we are to accept the definition of the word public as true on authoritative grounds, then, according to the analysis of the synonyms, interpretation of the definition, and understanding of the word, what makes a public is a group of people who have at least one thing in common. With a clear understanding of the public, we must consider the notion of logical consequence, as it pertains to such a notion. Something is said to be a logical consequence of another just in case it is impossible for the former to be true without the latter being the case (Barker-Plummer et al., 2012). What concerns us now is how the lack of uniform agreement is a logical consequence of the notion of public.

The primary issue is that the notion of public tends to be somewhat misleading when considering the stance on science and related issues while referring collectively to a group of *different* individuals as members of the *same* public. Besides, relying on this understanding of public as a



starting point to refer to the people as such exposes the conceptually inherent flaw of internal inconsistency or self-contradiction. As a result of the contradiction, anything may be derived, which is something to be avoided at all costs. Therefore, to avoid such a logical contradiction, we ought to abandon the traditional notion of public and declare that there can be no singular public; there are only multiple publics (AAAS, 2018).

The notion of "public" that I hold would be best understood as analogous to "myself watching this video of myself watching this video, ad infinitum." As it so happens, my analogy may be conceptually represented more succinctly by the notion of a fractal. Mathematically, a fractal is a macroscopic shape or object in which the overall abstract figure, pattern, or phenomenon comprises progressively smaller nested versions of itself when viewed microscopically (Stevenson, 2011). Much like the yield of a high-powered microscopic analysis of a frozen frame of the video of "myself watching this video of myself watching this video," or the continuous yet slow zoom examination of any fractal would reveal: there exist multiple successively smaller identical versions of itself. It is for this reason that, given the word "public" by definition must be comprised of ever-successively smaller publics, I used fractal to characterize the essence of public and adopted a fractal framework in an effort to comprehend them more fully.

If I construct an argument to support the claim that there are many publics, as mentioned and begin with the fact there is a lack of consensus among the public, then it may be more convincing to the reader. For example, borrowing just one potential issue of contention among the public in which there may only be two possible positions for members comprising a public to adopt, either everyone agrees, or they do not. So, unless there was complete unanimity (i.e., 100% agreement), then the people could be designated according to the position they supported, which would result in two groups. However, if each of the groups consisted of people who share a common position, then, according to the definition provided previously, each group would be considered its own public. In other words, we have discovered that the first public comprises at least two distinct publics. Furthermore, what was true of the first public must be true of each of the two new publics. Of course, continuing along this same line of reasoning would result in each subsequent public containing yet others, and so on.



The takeaway message from this thought experiment is that for each property or issue of contention there exist two or more sides; thus, necessarily there is more than one public. Furthermore, if the issue of contention were “what does science mean” or “how does one interpret science,” or even “what is your level of confidence in science,” then the results would be identical: the existence of a fractal public. Additionally, having multiple publics is consistent with the reality of varying interpretations of science as well as distinct levels of confidence in science. Given the aforementioned differences in confidence and meaning of science that exist in each public, it may be concluded that the relationship between confidence and public understanding of science is not merely one of association; the relation is one of cause-and-effect. Nonetheless, the cause and effect are not what most would believe. It is not the case that levels of confidence in science cause various meanings of science or how science is interpreted; I contend that the differing levels of confidence in science can be attributed to the different interpretations and meanings that science has to different people.

If there is to be any hope of society moving beyond behavior in the form of flawed reasoning, then we must strive for, and engage in, rational discussion. Moreover, if rational discussion requires there to exist a possibility of establishing inference-warrants, then all parties involved in the engagement must be clear about the sort of problem or issue at hand (Toulmin, 2003). Such clarity concerning a particular problem may only be achieved if there can be improvements made in the Public Understanding of Science (PUS). Thus, the process of improving PUS must begin with a concerted effort to remediate the faulty reasoning and unsubstantiated claims that have become the norm.

Despite the legitimacy of science and overwhelming evidence supporting climate change and anthropogenic global warming (AGW), many of the American public remain either skeptical or in complete denial of its truth (Dunlap, 2013). The degree of skepticism is much higher in segments of the public on the lower end of SES and educational achievement concerning the purported benefits of science and research and the astounding rate at which technological advancement occurs (AAAS, 2018). Nevertheless, despite the fact that skepticism is a qualitative characteristic that is both native to, and necessary, for science (Dunlap, 2013), in the face of existing evidence, complete denial is not.



That the public can remain in denial suggests a lack of appropriate knowledge, skill, and attitude for making judgments regarding such issues of scientific concern. Whether skeptical but willing to accept evidence, or skeptical and unwilling to accept any evidence, in order to legitimately claim improvements in the PUS have been accomplished, all members of the public ought to be equipped with basic scientific skills requisite for evaluating issues of concern. Thusly equipped with improvements concerning the PUS, there would genuinely exist a competent public comprised of informed individuals each of who are more likely to participate in fulfilling the role of citizen scientists (Mejlgaard & Stares, 2009).

Public engagement with science (PES) refers to opportunities for mutual learning and growth that comes about when scientists and members of the public meaningfully and deliberately interact (AAAS, 2018). That notwithstanding, PUS is a prerequisite for PES. Therefore, to remediate the deficiencies in knowledge (i.e., PUS) concerning the basic principles of logic, reasoning, and argumentation necessary for participation in rational scientific discussion (i.e., PES), I have designed a course curriculum addressing them. By availing the public of a seminar entitled “Fundamentals of Logic, Reasoning, and Argumentation for Public Engagement with Science (PES),” individuals who enroll and complete my course will acquire the acumen, ability, and attitude that are essential to contributing to decision-making related to issues of scientific concern. It is through the acquisition of such essential tools that, not only will learners possess what is needed in order to evaluate issues of scientific interest and concern, they will be capable of forming their own opinions and appropriately supporting their respective stances.

3. Student Factors: Potential Threats to Learning

Everyone at one time or another has had a learning experience, which consisted of them either mentally or physically doing things that led to changes in their knowledge, skills, or attitudes (Jones, Noyd, & Sagendorf, 2015). Regardless of the experience, many factors that influenced the outcome of their learning efforts. The previous learning efforts may have been either positive or negative depending on the individual and how they perceived it. No matter how they may have been perceived, such outcomes that comprise the backgrounds and experiences related to learning, culture,



family, self-esteem, and confidence, which provide the context within which learners exist. In addition, as a contextual framework within which learners live, background and experience also play a role in constructing or forming what they know, the attitudes they adopt, and any skills that they possess.

For any student learner, naïve conceptions, one's level of maturity, and his or her tendency to challenge authority are all products of their experience that may be categorized under *knowledge, skills, and attitudes*. Additionally, individuals of greater socioeconomic means may have more learning opportunities and exposures to learning than the less fortunate, which affords them chances to improve their attitude, correct knowledge deficiencies, or perfect a skill. Nonetheless, regardless of student SES and despite the many potential factors that have the potential to detrimentally impact the learning outcomes, there is one key aspect of related to my course offering that I claim effectively neutralizes most if not all the other potential student factors: the elective nature ultimately in my class. This class was deliberately designed according to principles of a learner-centered curriculum (Jones, Noyd, & Sagendorf, 2015) because it ensures that the final design is self-contained, which facilitates the process of learning when the course is offered by allowing every student enrolled to accomplish the primary course goals without requiring that attendees rely on prior experiences.

4. Factor Forms: Intentional Versus Unintentional

Indeed, there can be no way to know with absolute certainty who shall attend my course. As an unknown, it becomes even more clear why as course designer I insisted upon the learner-centered curriculum: without knowing the “who” (i.e., persons who will enroll) it would be nonsensical to assume knowing “what” in the form of science background as prior experiences anyone will have. Nevertheless, whomever these students will one day be, along with them will come various challenges that may hinder the learning process. Although many potential types of challenges may exist and could justifiably be worthy of our attention, I feel that it is necessary to categorically



distinguish between at least two main varieties that will present as challenges due to their potential to affect students' ability to achieve an educational goal. Dichotomizing the forms of challenge results in what I refer to as 1) Intentional Factors, and 2) Unintentional Factors.

Unintentional factors I claim would be those circumstances, outcomes, or experiences over which students exert little to no control. An example of an unintentional factor would be having been raised in poverty or a low SES as a child or suffering from a developmental disability. As opposed to unintentional ones as we have already mentioned, an intentional factor would be something over which one does have legitimate control, yet he or she fails to exert it for whatever reason. It is crucial to understand that, in such cases, a factor at play need not result from the commission of an act in order to qualify as intentional; because intentional/unintentional refer to the relation between an individual and factors with the potential to disrupt the process of learning or self-fulfillment, we may now include the omission of an act, which might be a direct result of intentional behavior and rightfully categorized under intentional factors.

5. The Case of Obstinacy as an Intentional Factor

As an example of an act of omission, for instance, were a student to exhibit obstinacy related to a naïve conception held just discovered by him in class to be impossible, the student's refusal to cooperate by responding with the appropriate response (i.e., inaction) would be considered intentional. Now, unlike unintentional factors, such deliberate stubbornness by a student in class allows me to infer that a reason –or more accurately, an absence of reason– for such behavior exists. I would argue that the absence of reason would be related to a lack of motivation, interest, or incentive. In other words, if the student had the motivation to acknowledge the naïve conception was incorrect, interest in it being incorrect or determining what is correct, or incentive to produce the correct response, then the intentional factor of stubbornness would cease to exist.

As a science educator, knowing that I would be unable to repair or replace any of the horrible experiences some students endured that may serve as unintentional factors (e.g., poverty) impeding both the efforts of students and myself would be disheartening. However, in the case of my course,

since any student will either have intentional, unintentional, or both factors to contend with while learning in my course, fortunately, by virtue of there being no enrollment costs, registration being entirely voluntary, and made available on a first-come-first-served basis, not only will the majority of unintentional factors be directly and effectively neutralized (e.g., SES), but given the voluntary signup, each enrollee had to be already motivated, interested, and have the incentive to do so. In this fashion, my course offering also attempts to indirectly ensure that the potential for any remaining factors to be present – intentional or otherwise – is significantly reduced before the course even begins. While not guaranteed to eliminate all the potential challenges in the form of factors, efforts were put into all aspects of the course that are guaranteed to eliminate some factors. Upon their elimination, these student factors no longer threaten to detrimentally impact the material being taught or learned in the class.

6. Learning Goals

Learning goals may be understood as what students should be able to accomplish upon completing a course of study (Jones, Noyd, & Sagendorf, 2015). The visible result of completing my course would be that attendees will be capable of performing their own independent assessment concerning scientific issues relevant to society using logical reasoning and argumentation.

A Thorough understanding of science basics and an ability to employ logic, reasoning, and argumentation routinely to facilitate learning. Ultimately, successful students will find that education becomes a process of self-propagation. For instance, individuals claiming to know A, B, and C, for example, should be able to employ the skills that they have learned and, relying on them as premises, derive D; then, with A, B, C and D, conclude that E is the case. Possessing the ability to determine for themselves what justification –if any– there may be for believing something, whether that something is, in fact, real, and claiming to know that something is hugely empowering. Moreover, from this starting point, they may metacognitively engage themselves deducing from what is already known to add to their knowledge base as well as assess whether new claims are consistent with what is already known and why



General learning goals (GLGs) for the course include the following: 1) ability to make logical decisions relying on available evidence concerning scientific issues; 2) be capable of forming their own opinions regarding public policy and contribute to dialogue on critical issues in public discourse; 3) employ the acquired knowledge and skill to determine the best course of action with regard to their behavior and of those for whom they are responsible including both relatives and the public.

7. Goal Descriptions

GLG 1 entails the use of logic, reasoning, and argumentation, to increase knowledge and to aid in decision-making according to a rational process that relies on available sources of evidence concerning particular scientific issues. GLGs 2 and 3 may be understood as giving students the tools needed to allow them to construct their own opinions regarding private (i.e., personal ethics) and public policy, thereby to equipping them with the ability to contribute to dialogue and discourse in the public forum. Of the GLGs, it is GLG 1 that serves as the primary learning goal for participants and is what guided curriculum design.

8. Summative Assessment

A summative assessment is used to evaluate the level of student comprehension and is given at the end of a course. Like the formative assessment, the summative assessment was aligned with the goal of the course. Aligning the summative assessment in such a fashion is akin to a method of validating that the course content, experiences, formative assessment, and proficiencies measure or reflect that students learned what they were supposed to learn. The summative assessment for my course will be the following project:

Given the available evidence regarding the phenomenon of global warming and climate change, conduct a review of the literature and choose 5 research papers claiming to support and 5 claiming to refute its occurrence. Then, analyze the evidence presented and using logic and reasoning, determine your stance on the issue and present an argument in support of it.

9. Learning Proficiencies

In order to achieve the goals of this course, attendees must possess specific knowledge, skills, and attitudes (KSAs). Without these KSAs, students will be unable to move closer toward the ultimate learning goals of the course. Each step of the way students will acquire these KSAs to the point of proficiency so as to progress; Thus, since progression hinges on students' becoming proficient through "the acquisition of KSAs," the KSAs are referred to as Learning Proficiencies.

Table 1 comprises the learning proficiencies (i.e., KSAs) for this course. The proficiencies in Table 1 have been categorized according to the Type by row and by column, which allows for a coordinate system of designation to describe each one.

Table 1 Descriptive Learning Proficiencies for Fundamentals of Logic, Reasoning, & Argumentation

Type	Knowledge	Skills	Attitude
Principle	Participants will be able to recognize the basic structure of an argument that comprises scientific evidence.	Construct a basic scientific argument.	Students will be self-efficacious (i.e., believe in their own abilities).
Concept	Students will be able to distinguish between valid argument and invalid argument.	Critical thinking skills (e.g., critical reading, evaluation of evidence)	Students will be motivated to use logic, reasoning, and argumentation as a tool for self-education and decision-making
Concept	Identify characteristic parts of a given scientific argument.	Critique a scientific argument of others and evaluate for validity, soundness.	Students will be comfortable
Fact	Students will be able to define and describe the characteristics of an Argument, Its Premises, Its Assumptions, Its Conclusions, Validity, Soundness, Deduction Rules, Derivable Rules.	Metacognitive skills (e.g., monitoring their own progress) - critique their own scientific argument and evaluate for validity and soundness.	

For instance, the facet of proficiency requiring one to recognize the basic structure of an argument comprising scientific evidence is located in row 2, column 2: row 2 (including header row) reflects that *principles* are necessary for proficiency while column 2 reveals that *knowledge* is required to be proficient, as well. The basis for the coordinate system I decided upon is the following. An *ability* to recognize an argument requires knowledge of its general structure. Recognition alone is the least that can be done and calls for neither *skill* nor does it involve *attitude*. Moreover, though this proficiency may rely on *knowledge* that is derived from the cohesiveness of *facts* that yield *concepts*, it is neither factual nor itself a concept. Since success in demonstrating proficiency, therefore, comprises *principles* and *knowledge*, which requires that one be capable, I propose that proficiency be conceived of as an *ability that results from a thorough understanding of the concepts derived from the knowledge of isolated facts*.

Although it does a wonderful job organizationally, Table 1 is descriptive. The descriptive elements in the table may be improved upon, in my opinion, by the adoption of an alternate framework. Instead of rightfully viewing learning proficiencies as merely being descriptive of the outcomes of a metaphoric “course goal equation,” I wondered whether altering perspectives on either the goal, the equation itself, or both would lead to greater insights. Ultimately, it would be changing my perspective on the overall equation that made the most sense.

Table 2 Reorganization and Mapping of Table 1’s Learning Proficiencies for Fundamentals of Logic, Reasoning, & Argumentation

Type	Beginner	Intermediate	Advanced
Attitude	Students will be motivated to use logic, reasoning, and argumentation	Students will be comfortable	Students will be self-efficacious (i.e., believe in their own abilities).
Knowledge	Participants will be able to recognize the basic structure of an argument that comprises scientific evidence.	Students will be able to distinguish between valid argument and invalid argument. Students will be able to identify parts of a scientific argument.	Students will be able to define and describe An Argument, Its Premises, Its Assumptions, Its

Skill	Students will be able to transcribe real-world scientific issues into the arguments that comprise them	Conclusions, Validity, Soundness, Natural Deduction Rules of Logic, Derivable Rules of Basic System of Logic (System K) Participants will be able to apply basic rules of logic in the assessment of simple scientific arguments. Critical Thinking (e.g., critical reading, evaluation of evidence) - critique scientific arguments of others, evaluate them for validity and interpret the results.	Judge scientific arguments as evidence, determining any consequences and their impact, recommending courses of action to be taken based on the judgment, and suggest public policy concerning scientific issues.	Metacognitive (e.g., monitoring their own progress) - critique their own scientific argument and evaluate for validity and soundness.
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By viewing each of the learning proficiencies as components of an overall goal equation that are individually necessary yet only sufficient together, the proficiencies have been transformed into what students ought to know, what they should be able to perform, and the attitude they should possess to allow them to realize the outcomes of the course. In this fashion, Table 2 displays the results obtained from revising my perspective on the information contained in each cell of table 1, which are mapped to the theoretical level of a successful student outcome.

Table 3 Angelo & Cross' (1993) Classroom Assessment Techniques (CATs) Among Those to Implement in the Assessment of Course-Related Knowledge, Skills, and Attitudes (KSAs).

Type	Beginning	Intermediate	Advanced
Attitude	Students will be motivated to use logic, reasoning, and argumentation	Students will be comfortable	31. Everyday Ethical Dilemma: Students respond to a case study that poses a discipline-related ethical dilemma 39. Process Analysis: Students outline the process they take in completing a specified assignment.
Knowledge	1. Background Knowledge Probe: short, simple questionnaires prepared by instructors for use at the beginning of a course or at the start of new units or topics; can serve as a pretest; typically elicits more detailed information than CAT2. .	2. Focused Listing: focuses students' attention on a single important term, name, or concept from a lesson or class session and directs students to list ideas related to the "focus."	3. Misconception or Preconception Check: focus is on uncovering prior knowledge or beliefs that hinder or block new learning; can be designed to uncover incorrect or incomplete knowledge, attitudes, or values
Skill (Analytic and Critical Thinking)	8. Categorizing Grid: student complete a grid containing 2 or 3 overarching concepts and a variety of related subordinate elements associated with the larger concepts	9. Defining Features Matrix: students categorize concepts according to presence or absence of important defining features	10. Pro and Con Grid: students list pros/cons, costs/benefits, advantages/disadvantages of an issue, question or value of competing claims
Skill (Synthetic and Creative)	13. One-Sentence Summary: students answer the questions "Who does what to whom, when, where, how, and why?" (WDWWWWHW) about a given topic and then creates a single informative, grammatical, and long summary sentence	15. Approximate Analogies: students simply complete the 2nd half of an analogy—a is To b as x is to y; described as approximate because rigor of formal logic is not required	16. Concept Maps: students draw or diagram the mental connections they make between a major concept and other concepts they have learned



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10. Conclusions

The effort was made to present the case for a course that was designed to address the need for improved scientific literacy through teaching the fundamentals of logic, reasoning, and argumentation for public engagement with science. The targeted audience includes adult students who are members of the public who are not considered scientists by profession. In addition to providing justification for the offering, the approach that will be taken toward educating students who enroll has been provided. Among the more compelling reasons creating such an enriching experience in the form of this course is the fact that interest in science is growing while scientific literacy is decreasing (Suleski & Ibaraki, 2010). Because science exists in the form of scientific theories, Logic, reasoning, and argumentation are necessary in achieving scientific literacy. Thus, scientific literacy is required for understanding, as well as engagement with, issues of scientific concern in any meaningful capacity.

With neither understanding nor engagement by the public (comprising yet other publics, which are themselves made up of still more publics), unfortunately, policies cannot be shaped by citizens. That notwithstanding, through the provision of opportunities for enrichment such as the course herein presented or others that are similar, those individuals who do attain a level of scientific literacy that allows them to understand and engage in matters of scientific concern place themselves in the unique position of being among both society's *benefactors* and its *beneficiaries* of public policy simultaneously. While everyone may not actively participate in the process of policymaking, one



this is certain: *policies made concerning scientific issues cannot be said to truly benefit those who fail to understand them.*

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Appendix A. Author biography

La Shun L. Carroll is a full member of Sigma Xi, The Scientific Research Honor Society. He received his Doctoral Degree, *Cum Laude*, from the University at Buffalo School of Dental Medicine. Subsequently, Dr. Carroll earned his Ed.M. graduate degree from the University at Buffalo Graduate School of Education. As an undergraduate, he graduated with a B.A. from Baruch College, *Magna Cum Laude*, majoring in both Philosophy and Natural Science. His publications include "*Theoretical Biomimetics: A biological design-driven concept for creative problem-solving as applied to the optimal sequencing of active learning techniques in educational theory*" in the Multidisciplinary Journal for Education, Social and Technological Sciences (October 2017), and "*A Comprehensive Definition of Technology from an Ethological Perspective*" (MDPI, 2017). Research interests include metaphysics, logic, science, technology, and education. Dr. Carroll was an Adjunct Professor at Saint Michael's College.