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Theoretical Biomimetics: A biological design-driven concept for creative problem-solving as applied to the optimal sequencing of active learning techniques in educational theory

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Abstract

The article introduces the author's concept of applying principles of biological design to drive creative problem-solving. It provides a brief background of the field of Biomimetics, which serves as a context for the reader to appreciate how it began with an established field upon which he constructed and adapted his concept to apply to human-made intangibles. A discussion of Theoretical Biomimetics specifies the differences between it and its predecessor. The final section provides the opportunity to see Theoretical Biomimetics in detail applied to education theory to address a problem related to student learning in higher education and how best to establish optimized sequences to implement evidence-based active-learning techniques to fill a void in the literature demonstrating from nature what has worked. The originality lies in the author taking a multidisciplinary approach to synergize a sequence of existing active-learning techniques and apply them to a new area in a new way.

Keywords

Biomimetics, creative problem-solving, educational theory, active learning, teaching methodologies, pedagogy

1 Introduction

What do Aircraft, CPR, The Camera, Eyeglasses, and Swimming all have in common? They all exist as results of the successful comprehension and application of data obtained

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from the observation of principles that guide biological processes or designs to create, develop, or advance human-made tangibles. If one wants to fly, then studying birds is the best option. Likewise, if the goal is to sustain life then understanding how life is sustained should provide guidance on which essential principles to incorporate. Therefore, it requires no stretch of the imagination to understand the potential benefits of studying and applying principles that govern biological processes and designs in nature to address problems of all sorts.

Problems do come in many forms, such as naturally occurring events. While it may not be the case that the conditions are the cause of the natural event occurring; the natural event occurs because of the conditions and may provide clues as to how best to deal with it in the future. Responsibility is either directly attributed (i.e., the cause of), or indirectly attributed (i.e., because of). Although it is unfathomable to either encounter or create a problem for which there is no solution, without insight into the workings of the most creative of problem-solvers known to man, it may prove too daunting a task to solve on our own. Our reality consists of a constant juggling act where we become aware of a problem only to reveal another problem in the process of solving the first. There is apparently no way to address every problem without creating "new" ones. Nevertheless, there may be hope for finding a new application that borrows from an existing field known as Biomimetics, which the author has envisioned and he believes has the potential to be a discipline in its own right.

2 Biomimetics: The Established Field

Architects have studied plants and incorporated these principles into the structural design of towering edifices (Knippers and Speck, 2012). Likewise, engineers can apply principles learned from data obtained observing wing span and migration in nature to design wings for aircraft with specific purposes in mind, such as long flights, fast flight, and energy minimization (Rasmussen et al., 1995). The most efficient and enduring things made by

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man are modeled with nature in mind. It is no surprise why Biomimesis (Bar-Cohen, 2006), or mimicry of natural processes and designs to create structures and materials (tangibles), has been recognized and widely adopted as both an effective and efficient approach to human-made things (Bond et al., 1995). With this in mind, the author wondered with the completely logical application to vehicles, buildings, aircraft, and other human-made tangibles, "Why couldn't biomimetic principles be applied to the creation of human-made intangibles with as much effectiveness?" From this, natural and biological phenomena serving as the basis for conceptual problem-solving was born.

Although the author cannot be credited with the concept of using biological design or processing approaches to creating human-made tangibles also known as Biomimesis, the author is contributing the idea of using biomimetic principles as an approach to creating, developing or advancing human-made intangibles such as theories. Researchers have studied biological processes and design in order to understand them and explain, which we know as Science. Many have certainly taken Science a step further by exploring natural processes and designs and applied principles to create human-made things or tangibles, which is known as Biomimetics. The author has taken Biomimetics one step further by implementing the principles of biological processes and designs to create, develop, or advance human-made intangibles.

The author has not come across anything in the literature. Whether it will come to be known as a branch of Biomimetics, or be to Biomimetics what Biomimetics is to Science is yet to be known. Nonetheless, the author describes and defines his contribution as *the concept of the study and application of principles guiding biological processes and designs in creating, developing, or advancing human-made intangibles* and calls it Conceptual or *Theoretical Biomimetics*.

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3 Theoretical Biomimetics: The New Field

Nature does not operate in terms of right, or wrong, with respect to processes or design; man interprets them as such relative to subjective experience. We have studied things that are good or work well in nature and applied the underlying principles to the development of human-made physical processes and designs successfully with good reason. Nevertheless, as much can be learned from how biological processes and designs that are deemed inadequate or ineffective operate.

As an example, for scientists to study the underlying biological principles of the "pathological" processes of metastasis in malignancies and apply them analogously to create, develop, or advance a human-made cascading system responsible for interception, encoding, encryption, and dissemination of information would be considered Biomimetics since the resultant application would be tangible. The point that the author is making is that when biological processes and design work well using them as inspiration is a good idea. However, it is when these biological processes and designs are violated then studied, as in the case of malignancies, that we have the best opportunity to capitalize on the potential for the greatest breakthroughs. Mother nature does not often have design flaws, and when she does, they are not many. To study and learn about how they affect her and how she handles them reciprocally the author feels would provide so many answers to problems that we are yet to encounter and is why "conceptual" problems should be explored with such abstract intellectual framework. It is with this approach in mind that the author employed Theoretical Biomimetics to conceive of an abstract yet creative approach to establishing a sequence for implementing evidence-based active learning (Bonwell and Eison, 1991) techniques to synergize student learning and achievement in educational settings.

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4 Application of Theoretical Biomimetics to Education

For the first demonstration of how Theoretical Biomimetics may be used in creative problem-solving, the author attempted to address the issue with student learning in higher education after reading a disturbing fact. Research conducted on more than 2,300 undergraduates found that 45 percent of students show no significant improvement in the key measures of critical thinking, complex reasoning and writing by the end of their sophomore years(Arum and Roksa, 2011). Something definitely in need of revisiting, according to this statistic, is how the process of educating students occurs in the classroom. So the author contemplated on the issue as an intellectual exercise to put Theoretical Biomimetics to the test.

The approach that the author took was to conceptualize how to establish a sequence for implementing well-accepted, evidence-based active learning techniques to synergize the educational process. The goal was to devise a "recipe" for instructors to use in the classroom, which could provide guidance based on desired outcomes, materials taught, or time constraints. Nevertheless, there will be some who oppose implementing such a thing, and the author has already expected naysayers to anticipatorily criticize this approach as being too mechanistic and rigid to be of any practical use to educators. The reader will be able to see that this could not be any more inaccurate a statement if they understand the what natural process inspired the idea.

4.1 Selecting a Natural Process for Comparison

Many studies advocate active learning techniques or strategies individually. Nevertheless, though there are lists that indicate the types of things educators are recommended to incorporate, the author found nothing close to an established protocol or flowchart detailing a sequence of steps in which to implement the techniques. Therefore, the author set out to

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integrate some of the best techniques to include from the literature and figure out how an optimal sequence might be modeled.

The optimal sequence was born of the idea that, like ingredients for a recipe that are added in a specific order to yield optimal results, there must be an optimal order to introduce active learning techniques. More specifically, there must be an optimal order or sequence for different types of educational outcomes, various kinds of subjects, and different time constraints at the least. That notwithstanding, the key was to determine which natural biological process or design could be superimposed on the learning process successfully. After much consideration to natural processes whose design could provide the scaffolding necessary to implement an optimal sequence, the author determined he would model the instructional and learning process after his personal experience with a type of cardiac arrhythmia known as Supraventricular Tachycardia (SVT).

4.2 Biological Process, Design, and Solution

Although there exist varieties, SVT may be explained as a reentrant loop in which nerve impulses occasionally in the heart are conducted through accessory pathways at different rates allows the faster one to travel back up on the path used by the slower one instead of continuing in the original direction (Badhwar, 2010). The author has had this condition his entire life. Those unmistakable rapid heartbeats were more annoying and frightening than anything. What made having an episode or SVT event so frustrating, yet intriguing, was how it occurred.

The author was unable to pinpoint what triggered them due to seemingly unpredictable occurrences. He was to avoid anything that increased heart rate because the faster the rate, the increased likelihood and episode would occur. The author had to wear a Holter Monitor continuously for a period to be able to record an event before an official diagnosis was confirmed. Eventually, while wearing the monitor 24hrs daily, the author had an episode

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that was recorded for the author's cardiologist who confirmed the diagnosis of Supraventricular Tachycardia.

When this occurs, the nerve impulse becomes trapped in this "reentrant loop" resulting in tachycardia and the associated symptoms that are experienced (Colucci et al., 2010). Trying to "break" the episodes when the author first had them, the author noticed that it seemed as though the longer the author had an episode, the easier it was to break it. There was something about spending more time in the reentrant loop that the author believed made escaping or "breaking" it easier. The author had success utilizing the Valsalva maneuver as needed with a daily regimen of Beta-Blockers. A Valsalva maneuver is one method to break the SVT episode that involves trying to forcibly expel air while bearing down against a closed glottis to slow the heart rate and break the reentrant loop (Pandya and Lang, 2015). Beta-blockers are a useful class of drug routinely used to prevent the onset of the reentry phenomenon that occurs with SVT by keeping the heart rate low by depressing nodal automaticity and inhibiting function (Kowey et al., 1987).

4.3 Abstraction and Application: Sequence is Everything

After the author had finished writing sections of this paper that he had not started, he began to format the completed sections he had not yet written. Next, the preceding sections that followed were what motivated him to come up with the idea to start writing about Theoretical Biomimetics in the first place. If the reader finds something not quite right or is having difficulty comprehending the previous two sentences, then author's point has been made: Sequence is everything. Moreover, if those same two sentences made sense to the reader, the author's point has also been achieved. He or she was presented with a group of individual words serving as information inefficiently juxtaposed that the mind rearranged in the most appropriate sequence to result in the information being intelligible and useful.

Whether it is DNA, coding for amino acids, speech, and conversation, or logic and mathematics, sequences determine economy, effectiveness, and efficiency. Even with culinary arts like cooking and baking, creative arts like dance and drawing, construction, architecture, or simply daily activities like getting dressed and ready to work, there is not a single aspect of existence that has not been affected, inspired, or optimized by sequencing. The author believes that as important as individual active learning evidence-based techniques may be, without established sequences in which to implement them they have nothing more to offer. Unfortunately, their full potential to collectively become greater than the sum of individual parts will never be realized. Theoretical Biomimetics aims to prevent that from occurring and is a prime example of how concept abstraction and application works.

Theoretical Biomimetics led to the abstraction of the biological process, design, and therapeutics involved in SVT to act as a framework for conceptualizing how one might best sequence evidence-based active learning techniques to optimize student learning, achievement, and educational outcomes. Analogous to individual ingredients each of which has individual properties when combined in a variety of sequences that yields specific results, the author believes that the particular arrangement or sequence of steps implemented in an optimized instructional method will lead to different outcomes. Experiments will be needed to validate which sequences are best for particular disciplines, educational goals, student learning types, and time requirements.

It must be stressed that the author is not advocating mechanical rigidity as some may contend. Active learning does require some flexibility, and the author has conceptually accounted for that in the process of establishing a sequence. One must remember that all that is minimally necessary for a sequence are two techniques where one must precede the other. In this fashion, the overall optimal sequence of techniques will be determined by combining the results from a series of individual sequence experiments performed on pairs of techniques at a time. Conducting the experiments this way not only will allow an overall

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optimal sequence, but technique-pair results individually can be organized such that algorithms may be formulated to suggest sequence choices for which techniques work best when immediately following others. Ultimately, these flow diagrams for use by both educators and students alike will facilitate instruction and study while simultaneously providing the sort of flexibility required to deal with ever changing classroom dynamics.

4.4 Selected Active Learning Techniques

More than a quarter century ago a review was done, which concluded that traditional lecture methods were not as effective as interactive discussion approaches in significantly improving retention, interest, and participation among students (McKeachie, 1987). For a while now there has been a shift in favor of incorporating more dynamic or active techniques categorized as Active learning. Active learning techniques are activities designed to get students involved in doing things and thinking about what they do (Bonwell and Eison, 1991).

The author believes that characteristics of an optimal sequence of active-learning techniques should include that which minimizes the likelihood of students becoming stuck in a metaphoric "reentrant loop." Additional features that should be built into the optimal sequence is that, in the unfortunate event that students do become stuck having to "reenter the loop," the optimal sequence should allow correction of weaknesses before students progress. Incorporating features like employing demonstration (Milner-Bolotin, 2007), think, pair, share (Mills, 1995), and classroom assessment techniques (Angelo and Cross, 1993) will ensure that students will have the opportunity to comprehend.

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Table 1 Example of instruction sequence using active learning strategies

Active Learning and Evidence-Based Techniques	Step in Sequence
Classroom Assessment	1st
Teacher Expectation	2nd-3rd
Explicit Teaching	4th
Demonstration	6th
Small Portions of Info	6th
Interactive	7th
Group Collaboration	8-9th
Summative Assessment	10th

4.5 Theoretical Biomimetically Suggested Sequence in Which to Implement Techniques

The steps involved in the Optimal sequence that the author suggests are as follows: (1) the teacher administers a diagnostic assessment to determine individual and class baseline levels with respect to the material to be covered in the course, (2) the teacher must assume students are capable; initially assuming the opposite in the absence of proof is self-defeating and self-fulfilling, (3) based on the assumption they are capable, he or she establishes high expectations for the students, (4) the teacher must be sure that expectations are clearly communicated (Teaching) and incorporate students teaching into course goals, (5) the high expectations imply confidence in students who then feel obligated to meet these expectations and fully commit to the educational experience, (6) having obtained student commitment, the educator begins instruction with ice-breaker activity that ties into the topic followed with an optimized sequence pair of demonstration (Milner-

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Bolotin, 2007) and deconstruction (Rosenshine, 2012), or any other appropriate pairing of active learning techniques determine using an algorithm for the allotted time, material or educational outcome desired, (7) students are encouraged to ask questions to solidify understanding of the material immediately afterward making the process interactive or dynamic. The instructor will reciprocate with purposeful questions appropriate to ability level, (8) students may then have an opportunity to demonstrate they understand, which gives students a chance to allow for teacher feedback, modification, and refinement before misconceptions are set in. This step displays the ability students have to teach one another (Paul) and collaborate with each other about what they have learned (Johnson et al., 1991) [Steps 6 thru 8 are the reentrant loop that gets repeated and students only move to the next step after full comprehension, and students' total commitment is positively reinforced by comprehension resulting in a continued effort to thoroughly master material], (9) the educator tests for students' mastery, which they may readily exhibit by applying what they have newly mastered to address novel problems. Mastery is defined by knowing what to do, how to do it, and why it is done the author coined "The Interrogative Trinity," and (10) the demonstration-deconstruction of material to allow students to comprehend and engage themselves in doing serves a dual purpose: To display material knowledge for assessment while building confidence, and to reinforce understanding of the material, which also builds confidence.

All components of an optimal sequence will be substantial. Nevertheless, the analogous reentrant loop design overlaying steps six to eight are the heart of the sequence and continues indefinitely until the material is mastered by the student. Each cycle of reentry reinforces learning the material such that subsequent cycles become less likely while permitting progression in the most efficient manner possible. This design will ultimately lead to the successful application of newly mastered material to address new problems by ensuring identified weaknesses are corrected before progressing.

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5 Conclusion

The suggested sequence of techniques composed of sequence pairings serves only as an example and has not been validated experimentally yet. Once data is obtained, it may be found that group collaboration yields the best results when following demonstrations as a sequence pair, in which case the sequence above can be further optimized by rearranging the techniques to reflect this. The sequencing process is dynamic and as different variables are discovered needs to be flexible enough to accommodate such newly discovered information. The author's concept is structured, yet flexible enough to meet such demands.

The author's response to criticism about his "recipe" of sequence pair optimization being too rigid and mechanical to be practical is best understood with an analogy to culinary training. The critics should know that "recipes" are to be considered to be structured, sequenced steps that provide roadmaps to guide aspiring chefs. These established protocols have been tested and sequenced based on the individual ingredients and what result is desired. For instance, when preparing a dish that consists of a liquid ingredient and a finely ground starch ingredient, there is an enormous difference between adding the liquid to the starch and adding the starch to the fluid. One sequence with the pair of ingredients results in a clumpy consistency while the other leads to a smooth consistency, which is why knowing that one wants to achieve a certain result requires that a specific order be followed and is exactly what a recipe provides.

Important to realize, however, is that a recipe containing five ingredients consists of units composed of four sequenced ingredient pairings. Eventually, through understanding why the ingredient pairs in a recipe are sequenced a certain way the novice chef will transition from the apparent rigidity of an exact recipe to the next level of improvisational cooking. If the reader has ever had the opportunity to witness an improvised meal made by a chef, then he or she undoubtedly was in awe at what was accomplished. To the unfamiliar, such improvisation may seem random and unstructured. However, the spontaneous dish was created with microstructures.

The multitude of culinary complexities one observes in end dishes derive from the chef's ability to employ an algorithmic approach subconsciously. This tree is comprised of sequencing paired ingredients such that given the availability of N number of ingredients and a result in mind, they have at least N! many ways to order them individually. That is, in the case of using eight ingredients to keep it simple, the chef has a total of eight factorial, or 8 x 7 x 6 x 5 x 4 x 3 x 2 x 1 = 40,320 possible eight-ingredient sequences. The 40,320 total permutations composed of sequenced pairings means that there are N(N-1) = 56 distinct sequenced pairings available to combine to yield the global order. It is the ordering of sequence pairs by the chef that produce the relatively endless possibilities when one accounts for the actual N ingredients available in any well-stocked chef's environment.

As instructors who are tasked with putting structure in students, utilizing a recipe to provide a structured approach is the most efficient method convey information. With our hypothetical chef analogous to instructors who have at their disposal N number of actual evidence-based active learning techniques, given N techniques and an outcome in mind, they have N! many ways in which to sequence the techniques overall using N(N-1) sequence pairs to achieve their goal. The example used eight ingredients intentionally to draw a comparison to an existing binary system in common use. The same way zeros and ones are employed in groups of eight to encode an alphanumeric character, each node of any eight ingredient sequence will be yes-no, or zero-one, such that active learning sequences may be conceived of as strings of a combination of decisions incorporating anywhere from no techniques (i.e., all no's) to all eight (i.e., all yes's).

So how might this work for active learning techniques at an instructor's disposal? Let us assume that data have been obtained experimentally for sequence pairs that rank them according to effectiveness using a zero to five score; zero is less efficient, and five is most effective. Certain techniques are obviously more appropriate to begin sequences, such as classroom assessment techniques (CATs), which can be used to obtain a baseline, are anonymous, ungraded, and for planning lessons. So, we select CAT, which is technique

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one. Although there are seven techniques to choose to follow technique one that we selected, evidence on pairings to which we refer shows that when technique four or seven follows the results are greatest. We then select number four and have our first sequence pairing, which we have chosen to provide the best results when used in this order. Our next technique must follow number four. So we consider the remaining sequence pairings with techniques that follow four and select the pair that provides best results according to evidence. In this case, for example, the best results are obtained when technique six follows four. Therefore, we have techniques sequenced one-four-six obtained from the sequence pairings of one-four and four-six.

Utilizing a binary system of visualization, a row of eight nodes in numeric order left to right would indicate sequence pair one-four by yes under one and yes under four. To represent four-six, a yes would be in the node underneath four and six as well. When combined, nodes for one, four and six would result. To represent the inverted pair four-one, for instance, the nodes under one and four would be no and all others yes. In this manner, a pair and its inversion could be represented correctly. The reason that the author mentions how this may be done is to show how easily data obtained from experiments could be used to devise an algorithm for active learning decision-making programs to assist educators in choosing the most appropriate sequences for their desired purpose.

The utilization of an algorithmic approach to incorporating active learning and evidence-based techniques will help instructors select optimal sequences of any length based on desired outcomes, time constraints, and material covered using available evidence-based data from individual pairings. Contrary to what critics may believe, although particular “recipes,” or sequences, result in unique outcomes that can only be achieved with one order, there is no rigidity at all since sequence pairings are the units of which exact recipes are comprised and may be rearranged in nearly any order imaginable. In fact, sequencing is the opposite of rigidity; it provides flexibility as well as structure instead of guesswork and its associated unpredictability.

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The field of Theoretical Biomimetics as envisioned by the author allows individuals to become intellectual chefs of creative problem-solving. The examples from which to draw inspiration abound and their longevity are a testament to their brilliance. Despite conceptually being in its infancy, there is so much potential for Theoretical Biomimetics to blossom into a full-fledged field with the capabilities to create and develop both human-made intangibles directly, as well as human-made tangibles (i.e., Biomimetics) indirectly. In this fashion, Theoretical Biomimetics not only possesses a "meta-" aspect that will result in theory about theorizing and concepts on how to conceptualize, but the author conceived of it after what inspired its development yet it will be the inspiration for the creation of that which the idea that inspired its own creation was supposed to do thereby surpassing it! It is hoped that the author's ideas and article have inspired the reader. If there is one thing that the reader should take from this paper, it should be to understand the importance of sequence in that coming after does not preclude the possibility to take one further than that which has come before.

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