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Examining the Effectiveness of Principles of Biology Laboratory Course According to Vision and Change and MCAT Standards

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Abstract
The American Association for the Advancement of Science (AAAS) met in 2009 to hold the Vision and Change (V&C) conference to organize the Biology education under common concepts and competencies. The concepts direct content knowledge, while the competencies direct acquisition of cross-disciplinary skills Many undergraduate biology majors choose to pursue graduate training in health professions - including medicine . The American Association of Medical Colleges (AAMC) released a document describing content and abilities needed to be successful on the Medical College Admissions Test (MCAT). The MCAT is divided into four sections: one critical analysis section, and three science sections. The AAMC document outlined three foundational concepts to biology and four skills applicable to all science sections and bear many similarities to the core concepts and competencies of V&C. This study sought to qualitatively analyze the similarities between the MCAT and V&C standards, and examine how they apply to Harding University's introductory biology lab, Principles of Biology Laboratory. Significant overlap was seen between the V&C and MCAT principles, emphasizing the importance of learning these lessons. The Harding University Principles of Biology lab integrates many of the tenets of V&C and the MCAT in each of its lab activities to ensure a holistic understanding of biology and prepare students for their future as it relates to the field. The bacterial interactions lab was examined specifically and included quantitative reasoning, modeling and simulation, communication and collaboration, structure and function,, while also preparing students for techniques used in upper level courses. The study plans to quantitatively examine the perceived effectiveness and actual effectiveness of the course to students who have taken it. This will ensure students are adequately prepared for their future as it relates to the field and further refine the course to ensure effective curriculum is being used.

Introduction

Biology is a broad field of science, encompassing a wide range of specialties including ecology, physiology, and cellular biology. Even at the undergraduate level, it is crucial for professors to prepare students for future courses and research, as well as preparing pre-professional health students for their future pursuits. Students enter the class with a wide array of interests and goals, ranging from various types of research, to teaching, to health care fields. Students from these classes have desires to become future nurses, pharmacists, doctors, physician assistants, and other similar practitioners.

<u>Vision and Change Conference</u>

In 2006, the National Science Foundation (NSF) and the American Association for the Advancement of Science (AAAS) saw a need to establish essential biology principles, which led to the *Vision and Change in Undergraduate Biology Education* Conference in Washington, D.C. in 2009 (Brewer & Smith, 2011). This national conference prompted scholarly discussion about the content biologists should know, providing a standard for the field that has since proved to be a tool for biology education. Implementation of these principles has led to refinement of undergraduate level education, integration of actual research methods into courses, assessment, professional development, needed institutional changes, and the tools to facilitate these changes (Brownell, Freeman, Wenderoth, & Crowe, 2014). The conference listed five core concepts and six core competencies that are necessary for biology at any level (Brewer & Smith, 2011). These are meant to be instilled throughout the student's progression in learning, but are particularly needed at the introductory level, to form a strong foundation on which all the other knowledge can be built.

The core concepts were meant as crucial lessons to be learned so that all students have a baseline level of knowledge over the material, whereas the core competencies are meant as skills that should be gained by the students to be implemented in any individual pursuit in the future. These have become the eleven tenets that govern biological education at an undergraduate level, with every lesson seeking to improve the ability of students in one of these aspects.

Core Concepts	**Core Competencies**
1. Evolution	1. Ability to apply the process of science
2. Pathway and Transformations of Energy and Matter	2. Ability to use quantitative reasoning
3. Information flow, exchange, and storage	3. Ability to recognize the interdisciplinary nature of science
4. Structure and Function	4. Ability to communicate and collaborate
5. Systems	5. Ability to understand the relationship between science and society
	6. Ability to use modeling and simulation

The Vision and Change conference established these five concepts and six competencies for undergraduate biology, though they were considered important to all levels and disciplines (Brewer & Smith, 2011).

Further Education Development and Goals

Seeking to develop this further, biologists and educators have attempted to refine the ordering and structure of the curriculum across the students' four years of undergraduate study. A study conducted to determine the validity of the V&C principles and found that instructors agreed with the scientific accuracy of all concepts over 89% of the time in every case and the importance for students to understand the concepts over 95% of the time in every case. To improve this across all fields of science, they then prepared the BioCore Guide as a progression of the concepts from microscopic to macroscopic biology (Brownell, Freeman, Wenderoth, and Crowe, 2014).

The BioCore Guide incorporated feedback from more than 240 biologists and biology educators from various specialties to ensure validity and a wide degree of acceptance across the field. This was developed for various purposes, including identifying gaps in the curriculum, helping students see the “big picture” of biology, and assessment of curriculum. The researchers arbitrarily divided biology into three major subdisciplines: molecular and cellular biology, physiology, and ecology. The importance of the core concepts was discussed as they relate to the three subdisciplines, with the similar concepts being adjacent, to better aid in teaching at different levels (Brownell, Freeman, Wenderoth, & Crowe, 2014).

	Major Subdisciplines of Biology		
	Molecular/ Cellular/ Developmental Biology	**Physiology**	**Ecology/ Evolutionary Biology**
EVOLUTION	**Overarching Principles:** **All living organisms share a common ancestor.** **Species evolve over time, and new species can arise, when allele frequencies change due to mutation, natural selection, gene flow, and genetic drift.**		
	Multiple molecular mechanisms, including DNA damage and errors in replication, lead to the generation of random mutations. These mutations create new alleles that can be inherited via mitosis, meiosis, or cell division.	Mutations that change protein structure and/or regulation can impact anatomy and physiological function at all levels of organization.	The characteristics of populations change over time due to changes in allele frequencies. Changes in allele frequencies are caused by random and nonrandom processes--specifically mutation, natural selection, gene flow, and genetic drift. Not all of these changes are adaptive.
	Mutations and epigenetic modifications can impact the regulation of gene expression and/or the structure and function of the gene product. If mutations affect phenotype and lead to increased reproductive success, the frequency of those alleles will tend to increase in the population.	Most organisms have anatomical and physiological traits that tend to increase their fitness for a particular environment.	All species alive today are derived from the same common ancestor. New species arise when populations become genetically isolated and diverge due to mutation, natural selection, and genetic drift. Phylogenetic trees depict relationships among ancestral and descendant species, and are estimated based on data.
		Physiological systems are constrained by ancestral structures, physical limits, and the requirements of other physiological systems, leading to trade-offs that affect fitness.	Fitness is an individual's ability to survive and reproduce. It is environment-specific and depends on both abiotic and biotic factors. Evolution of optimal fitness is constrained by existing variation, trade-offs and other factors.
	Molecules (smaller and faster)	→	**Ecosystems (larger and slower)**
	Biological Scale		

Figure 3. BioCore Guide: a nationally validated tool for interpreting the core concepts of Vision and Change. We present the principles and statements that encompass the BioCore Guide, which have been built by more than 200 people in the biology community. The columns represent the three major subdisciplines of biology (molecular/cellular/developmental biology, physiology, and ecology/evolutionary biology), which are also depicted on a biological scale from the molecular to the ecosystem level. Each concept is represented by a separate box, with a set of overarching principles that cross subdisciplinary boundaries at the top and then two to three statements for each of the subdisciplines. (*Continued on next page*)

This is an example of one of the BioCore Guides developed to analyze the V&C core concepts. One was made for each concept, relating how it applies to three arbitrary subdisciplines of *biology ranging from a microscopic to a macroscopic scale. This was designed as a useful tool for development of undergraduate curriculum in various biology fields, as well as a way to see the interplay of the concept between specialties.*

Biology and the MCAT

Many students who undertake biology classes throughout their undergraduate experience, regardless of majors, are doing so to fulfill a pre-professional health track. If they are on a pre-professional health track such as pre-medicine, biology helps prepare the students for exams like the Medical College Admission Test (MCAT), Pharmacy College Admission Test (PCAT), Dental Admission Test (DAT), and Biology Graduate Record Exams (GRE), instilling deeper understanding of the biology behind medical treatments. Regarding medicine specifically, biology is the single most common major amongst applicants. Nearly 55% of medical school applicants in the 2018-2019 cycle were biology majors, with the next largest major of applicants representing just over 9% (Pre-Med Majors: Choosing a Specialty).

The American Association of Medical Colleges (AAMC) has released official information packets regarding the content and preparation of the MCAT. Four scientific skills were described in their relevance to designing the three science sections of the MCAT (chemistry, psychology, and biology). All of the four sections also included specific foundational concepts that the content was structured around as it related to that particular field (What's on the MCAT, 2020).

Scientific Reasoning and Inquiry Skills	**Explanation**	
Knowledge of Scientific Concepts and Principles	Demonstrating understanding of scientific concepts and principles.	Identifying the relationships between closely related concepts.
Scientific Reasoning and Problem-Solving	Reasoning about scientific principles, theories, and models.	Analyzing and evaluating scientific explanations and predictions.
Reasoning About the Design and Execution of Research	Demonstrating understanding of important components of scientific research.	Reasoning about ethical issues in research.
Data-Based and Statistical Reasoning	Interpreting patterns in data presented in tables, figures, and graphs.	Reasoning about data and drawing conclusions from them.

The American Association of Medical Colleges established these four skills as essential for each of the three science sections of the MCAT. Descriptions of the skills are shown to the right of the skill to elaborate on how they may be utilized. They are used in development of the questions and important for success on the chemistry, psychology, and biology sections of the exam (What's on the MCAT, 2020).

Biological and Biochemical Foundations of Living Systems Framework of Foundational Concepts and Content Categories	
Foundation Concepts	**Content Categories**
Biomolecules have unique properties that determine how they contribute to the structure and function of cells and how they participate in the processes necessary to maintain life.	Structure and function of proteins and their constituent amino acids.
	Transmission of genetic information from the gene to the protein.
	Transmission of heritable information from generation to generation and the processes that increase genetic diversity.
	Principles of bioenergetics and fuel molecule metabolism.
Highly organized assemblies of molecules, cells, and organs interact to carry out the functions of living organisms.	Assemblies of molecules, cells, and groups of cells within single cellular and multicellular organisms.
	The structure, growth, physiology, and genetics of prokaryotes and viruses.

	Processes of cell division, differentiation, and specialization.
Complex systems of tissues and organs sense the internal and external environments of multicellular organisms, and through integrated functioning, maintain a stable internal environment within an ever-changing external environment.	Structure and functions of the nervous and endocrine systems and ways these systems coordinate the organ systems.
	Structure and integrative functions of the main organ systems.

The American Association of Medical Colleges established these three foundational concepts and their content descriptions as the overarching lessons from which biology questions on the MCAT are written. Separate foundational concepts are used for the other sections (What's on the MCAT, 2020).

The test is divided into four sections, one of which is specifically about the biological sciences. However, all sections have included questions with content related to biology, for example, questions about neurobiology in the psychology section. The AAMC has stated that approximately 65% of the MCAT is just introductory level biology (What's on the MCAT, 2020). Certain sections of biology are covered more often than others. Particular emphasis is placed in cellular biology and genetics, with evolution and population biology being the least important (Rissing, 2013).

Principles of Biology Lab

Harding University's introductory biology course is called "Principles of Biology." The course was refined from the previous general biology course in 2018 to ensure biology majors and students of pre-professional health majors were being prepared for upper level biology courses. The course takes place over a full year, with a lecture portion typically taken in the fall and a lab portion typically taken in the spring. The lecture was aimed to introduce the material, while the lab helped to implement it and add a hands-on element to aid in the learning process. Labs are designed to reinforce lessons learned in the lecture portion, many coming from the biology education website, Course Source, which contains many pre-published labs.

One lab, the bacterial interactions lab, was designed by professors at Harding University, based on published research regarding interspecific and intraspecific interactions (Khare & Tavazoie, 2015). The lesson was aimed at teaching students about competition and cooperation, pipetting techniques, and population growth modeling (Foster & Bell, 2012), (Hibbing, Fuqua, Parsek, & Peterson, 2010). Bacteria was cultured in a broth, then removed by centrifuge after having partially metabolized the nutrients present. Then, two samples containing either a new species or the same species were introduced to the broth. Students would measure light absorbance at a certain wavelength specific to the bacteria to indirectly measure the bacterial population in a sample and model it with a population growth equation. Students would work with a group and write a lab report on their results. Students would have to do research and examine important factors like the broader impact of the experiment, such as bacterial interactions and the gut microbiome (Rakoff-Nahoum, Foster, & Comstock, 2016). We chose this lab as an example lab for analysis because it was designed by professors in the department and is not yet published.

Method

A nonexperimental, mixed methods approach was taken to the study. We began with qualitative analysis of the Vision and Change core concepts and competencies and their similarities to the MCAT foundational concepts and skills. These were then applied to the Principles of Biology lab course to see if the curriculum met the standards. This was done primarily using the bacterial interactions lab as an example.

The quantitative portion of the study will take place during the fall semester of 2021 at Harding University to ensure a larger sample size and more accurate results. The sampled population consists of undergraduate students from Harding University who have taken the Principles of Biology lecture and lab. Majors include, but are not limited to biology, chemistry, exercise science, and medical humanities. Students either majoring in biology or intending to go into a professional health field must take this course.

One convenience sample has been designed to survey students one, two, and three years removed from the course to examine how effective they believe the course to have been at teaching its intended lessons. It was researcher designed and has been submitted for Institutional Review Board approval and will be distributed by Google Forms. The survey contains informed consent and five demographics related questions and 26 questions pertaining to how effective they believe the class to have been in specific areas. The demographics ask when they took the course, their current classification, their major, and whether or not they are pre-professional. This data will be analyzed with a two-way analysis of variance (ANOVA) test comparing year taken and major, with $\alpha=0.05$ and a 0.95 confidence level. The first set of questions are scored on a six point, descriptive Likert scale with the following descriptions:

Disagree without exception
Mostly disagree, but I can think of some cases where this might be true
I would disagree with this statement more strongly than I agree
I would agree with this statement more strongly than I disagree

Mostly agree, but I can think of some cases where this might not be true
Agree without exception

This descriptive scale was designed to ensure students understood the intended meaning behind their answers, rather than a numerical scale which we believed could have led to some degree of miscommunication. Students will answer one of these options to each statement on the survey, and the answers will then be assigned a numerical value of 1-6 (disagree-agree) for measurement purposes.

The second set of questions are designed to test which course students attribute growth in interdisciplinary skills in and include four options: Principles of Biology/Lab, General Chemistry/Lab, Outside knowledge/Other courses, or I do not have this skill/this skill has not been well-developed during my time in college.

My pipetting skills improved during Principles of Biology Lab.	Qualitative
My ability to use the concentration and volume equation ($M_1V_1=M_2V_2$) to correctly mix solutions is more effective as a result of Principles of Biology Lab.	Qualitative
I understood the importance and application of the dilution equations (such as $M_1V_1=M_2V_2$) more after completing Principles of Biology Lab.	Qualitative
Principles of Biology Lab increased my understanding of basic principles of how living things interact after Principles of Biology Lab (e.g. inter/intra-specific interaction, competitions vs. cooperation, etc…)	Qualitative
I understood and could apply basic population growth trends after completing Principles of Biology Lab.	Qualitative
Principles of Biology Lab increased my ability to operate basic lab equipment (like the Vernier sensors) to gather reliable data.	Qualitative
I could better design an experiment, including	Qualitative

basic procedure and hypothesis, given basic information and a goal after doing so in Principles of Biology Lab.	
My ability to use published primary and secondary scientific articles increased as a result of Principles of Biology Lab.	Qualitative
I understand how bacterial competition can be important and applicable in a broader context after Principles of Biology Lab.	Qualitative
I can better design and perform an experiment with a group after taking Principles of Biology Lab.	Qualitative
I feel better prepared to analyze genetic/genomic data after taking Principles of Biology Lab.	Qualitative
I understand how to examine antimicrobial qualities of products better after taking Principles of Biology Lab.	Qualitative
I understand how metabolic byproducts (like CO_2) could be used to measure the processing of different carbohydrates better after taking Principles of Biology Lab.	Qualitative
Pipetting accurately	Interdisciplinary
Calculating dilutions using equations like $M_1V_1=M_2V_2$	Interdisciplinary
Using the Vernier probes or similar equipment for data collection	Interdisciplinary
Developing mathematical descriptions of phenomena such as population changes/trends	Interdisciplinary
Designing an experiment	Interdisciplinary
Reviewing primary and secondary sources for information	Interdisciplinary
Performing an experiment in a group.	Interdisciplinary
Ability to apply the process of science	Interdisciplinary

Ability to use quantitative reasoning	Interdisciplinary
Ability to recognize the interdisciplinary nature of science	Interdisciplinary
Ability to communicate and collaborate	Interdisciplinary
Ability to understand the relationship between science and society	Interdisciplinary

A list of the questions developed for the survey measuring perceived effectiveness of the Principles of Biology laboratory course. Questions labeled "qualitative" were measured according to the qualitative scale listed in the chart above and examined student's confidence in their understanding or abilities. Questions labeled "interdisciplinary" had four options of where the students felt they most gained the skill: biology/lab, chemistry/lab, other, or skill not present.

A second survey is being developed with objective correct and incorrect answers. This will measure the actual performance of students according to the skills being measured in the first survey. After further refining the questions, IRB approval will be obtained. This survey will be distributed via Google Forms and ideally will be sent out by course professors to gather data from students before the lecture portion of the course, after the lecture portion but before the lab portion of the course, and after the lab portion of the course. This data will allow us to model growth of ability over time and see student improvement over time. Repeated measures ANOVA will be used to account for the same sample changing over time, with $\alpha=0.05$ and a 0.95 confidence level.

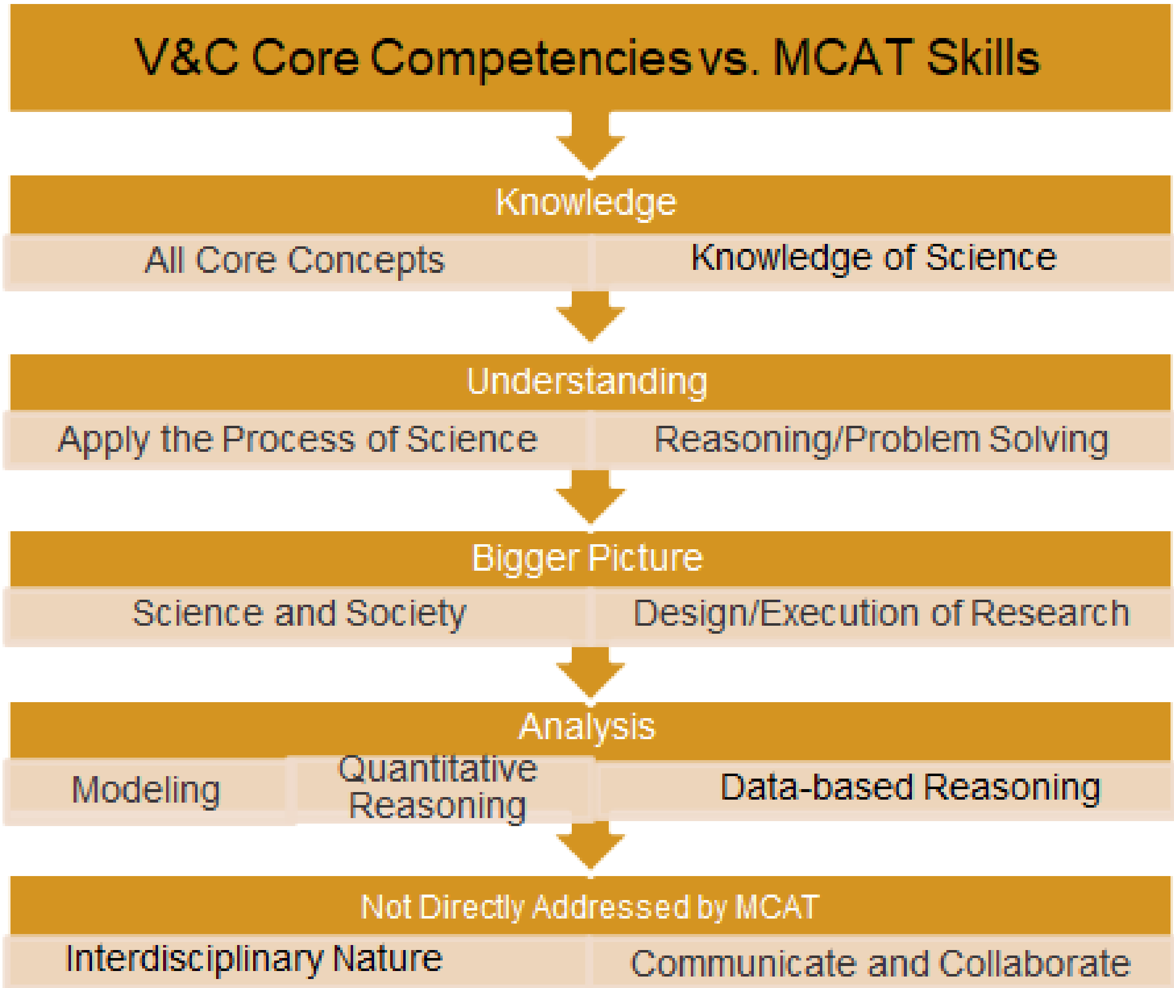
Results

A significant overlap was seen after qualitatively analyzing the descriptions of V&C core concepts and competencies as they compared with MCAT foundational concepts and skills, as well as examples of implementation and BioCore Guide interpretations. Regarding the core concepts, the majority of material seemed to overlap, as expected in the molecular biology field with concepts like information flow or transformations of energy and matter equating to unique properties of biomolecules for their common focus on macromolecules, genetics, and energy transfer through Adenosine Triphosphate (ATP). Evolution is not directly addressed on the MCAT but the concept may be indirectly or implicitly addressed through integrated questions on the exam. However, molecular and cellular biology seems to be the most pervasive on the exam, followed by physiology.

V&C Core Concepts and Equivalent MCAT Foundational Concepts	
Evolution	N/A
Transformations of Energy and Matter	Biomolecules are unique…
Information flow, exchange, and storage	
Structure and Function	Highly Organized Assemblies…
Systems	Complex Systems…

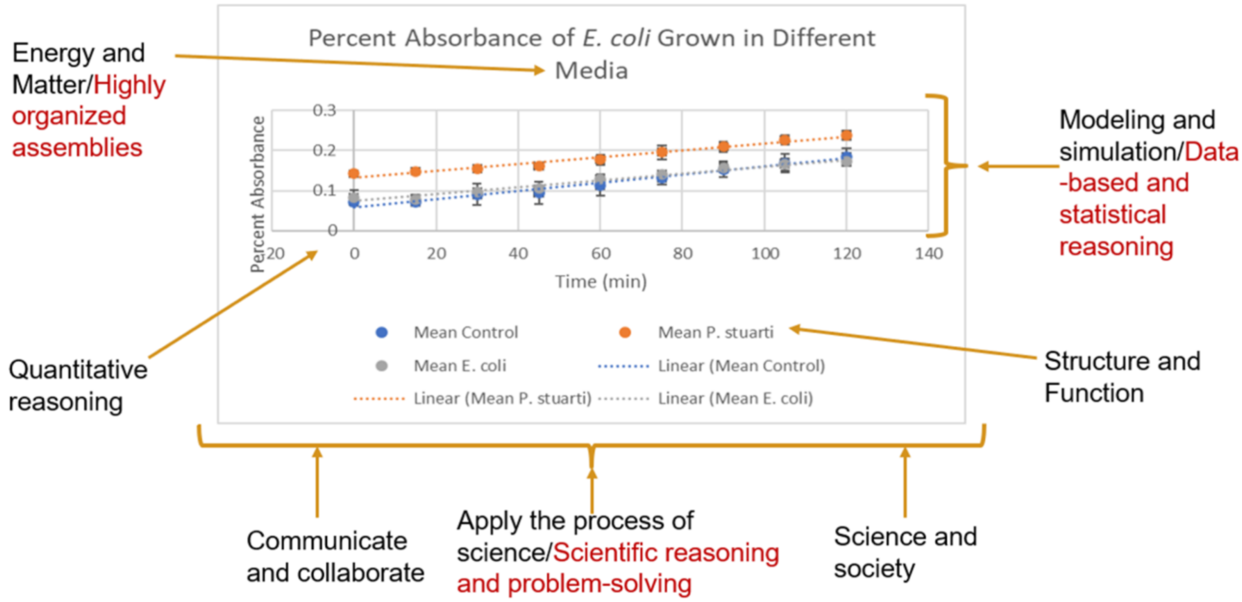
Equated V&C core concepts (left) and MCAT foundational concepts (right).

The competencies also seemed to show significant overlap with the MCAT skills. Knowledge of scientific concepts and principles seemed to simply encompass all the core concepts, as it is just the understanding of that material. Both V&C quantitative reasoning and modeling/simulation seemed to perfectly represent the data-based and statistical reasoning skill of the MCAT. Though communication/collaboration and interdisciplinary nature of science are not directly addressed by the MCAT, those are more implicitly understood. Almost all scientific studies require communication, though it cannot adequately be tested by an exam taken without collaboration. Similarly, each section of the MCAT incorporates material from sections besides their own (i.e. general chemistry having a presence on the biology section), seeming to indicate the interdisciplinary nature and relationship between science fields.



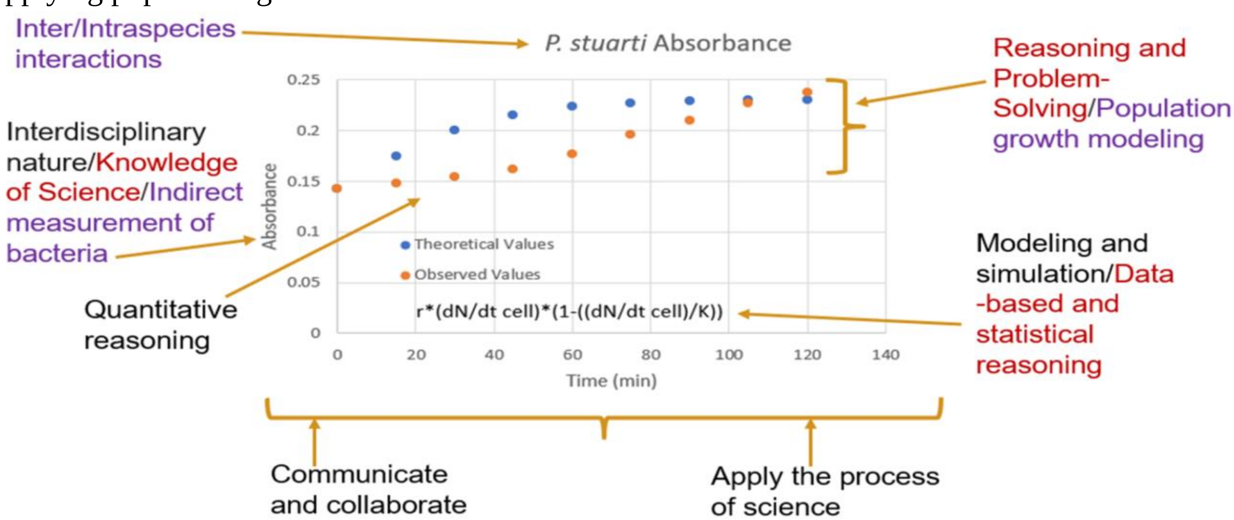
Equated V&C core competencies (left) and MCAT skills (right). Researcher classification of the idea behind each principle has been labeled above the compared competencies and skills.

When analyzing the graphs from the bacterial interactions lab, we found a high degree of integration of the concepts and competencies. Using a sample of the data from a student's run-through of the lab, we were able to assign applications of the concepts and competencies to the creation of the graph. The lab was done in a group and involved writing a procedure and applying it to a broader impact on the world. Therefore, the lab as a whole incorporated communication/collaboration, applying the process of science/scientific reasoning, and seeing the relationship between science and society. Quantitative reasoning and modeling were used to create the graph and examine trends in it. Even understanding the scientific concepts behind the lab, such as metabolism and prokaryotic interactions involved understanding basic structure/function of the bacteria, and energy/matter transformations.



Applied V&C and MCAT principles to the results of an example lab performed by students in Harding University's Principles of Biology course. V&C is displayed in black text, while MCAT is displayed in red text.

Furthermore, the lab also analyzed theoretical growth trends and saw how they compared with the actual growth trends. This ensured students utilized an equation to theoretically model their growth and apply it to a know trend, which emphasized skills like quantitative reasoning and modeling. Understanding the principles behind the absorbance as a measure for the bacterial population drew upon physics and chemistry principles to show an interdisciplinary nature. The lab was also successful in showing modeling differences between types of species, as well as applying population growth models.



Applied V&C and MCAT principles to the results of an example lab performed by students in Harding University's Principles of Biology course. V&C is displayed in black text, MCAT is displayed in red text, and skills specific to the course are displayed in a purple text.

Discussion

The overlap between V&C and MCAT principles helps to further indicate the importance of them for students. They are seemingly necessary for success in either biology research or a healthcare field. After analyzing the example lab, it is easy to see that it is nearly impossible to teach a single core concept or competency without being able to tie it to another. There is such a high degree of connection between all of the principles, that it is important to integrate them so they can be shown working together effectively.

It was important for the AAAS and AAMC to establish these tenets, as well as tools like the BioCore Guide to exist and ensure biology has a foundation to build on. Many biologists are trained scientists but not trained educators (Choi, Saphier, & Anderson, 2016), and so having tools to guide lesson plans and assess students is crucial to future advancements in the field and polished professionals with a thorough understanding of their field. Numerous obstacles are at play in biology education, including student's conceptual understanding of imperceivable concepts or using tools from other fields like math , and so it is important to have tools to combat those (Singer, Nielsen, & Schweingruber, 2013) .

Vision and Change helped establish important educational practices that can help ensure biology education is effective. TIntegrated lessons, positive reinforcement, and hand-on learning through multiple methods are all necessary to best benefit students (McLaughlin & Metz, 2016). Some students may enjoy a bioinformatics lab, while others may prefer a wet lab, all because they just have different learning styles. Trying to reach students through a variety of teaching methods with lessons that teach multiple concepts and competencies will ensure students are able to connect with the material and understand that no lesson is an island to itself, but rather connected with a much larger world around it.

Table 1. Vision and change tenets of educational practice.

Action Item	Outcome Goals
Integrated curriculum	• Introduce scientific process. • Teach core concepts in the context of engaging real-world problems.
Student-centered learning	• Actively engage students via multiple teaching modalities. • Utilize evidence-based teaching practice based on sound research.
Promote change to campus culture	• Involve students, faculty, and administrators. • Reward research and innovation in teaching. • Support training of biology educators.
Involve the wider community (workforce, nonprofits, etc.)	• Students experience authentic, meaningful engagements with the processes, possibilities, and limitations of science.

Example chart of educational tenets of V&C from a discussion of future biology education techniques (McLaughlin & Metz, 2016).

As technology has developed, there has been an increased attention on studying fields like genomics and bioinformatics, coding, and other updated skills and concepts as they relate to biology. Taking genomics as an example, though it is not yet positioned as a core concept, it has become more emphasized at an early stage in biology education through early appearances in many textbooks, especially majors specific textbooks (Ledley, Ndung'u, Haughton, & Wernick, 2014). Biology is a living field, with new advancements and discoveries being made daily. It is important that students learn skills and lessons that are important as time is progressing. As developments arise, computational lessons may begin to have an increased relevance in biology education, prompting another examination of what is important for students to know in biology.

Biology and medicine have always had significant overlap, since an understanding of biological principles is essential to understanding physiological problems and solutions. Some have even argued for integrating some medical related lessons into undergraduate biology courses. Aside from just the science, discussions about medical ethics that are used in medical schools could be adapted and used in undergraduate courses to involve students and examine science as it relates to the world around them (Dasgupta, 2017).

Measuring the effectiveness of the courses is important to improvements in curriculum. It is important for educators to examine the lessons being used to ensure they are teaching material effectively and that students are learning it well. Tools have been developed to assess student learning of the core concepts and can be easily used to test students understanding of V&C concepts. Testing can range from the Biology Card Sorting Task or the Bio-MAPS Assessment tools, and can help assess at a course or department level (Branchaw, et. al, 2020). This can help ensure students are learning and the curriculum being used is effective, or guide educators to a more effective method.

TABLE 1. Features of core concept assessment instruments

	Biology Card Sorting Task	Biology Core Concept Instrument	Bio-MAPS Assessment tools
Core concepts assessed	All, except for systems	All	All
Format	Physical or virtual cards	Hard copy or online biological narrative with TF/I and open-ended questions	Online multiple T/F questions; students answer a subset of 15 questions
Time to administer	–50 minutes	–20 minutes per BCCI narrative	–30 minutes
Grading	Automated analysis in CARDS online system	TF/I—automatic analysis; Open-ended—rubric grading; generates identify, apply and connect scores	Automatic analysis generates report by *Vision and Change* category
Scope of assessment	Course and departmental level	Course and departmental level	Departmental level

Example summary chart of assessment methods for the V&C core concepts from a descriptive analysis of them (Branchaw, et. al, 2020).

Future research is being planned to collect and analyze data from the perceived effectiveness survey, as well as to refine and send out the objective effectiveness survey, though IRB approval must first be obtained. Ideally, if results are good, we hope to be able to examine students at other universities at the same level and see how they compare with Harding University students. This allows for a deeper understanding of the effectiveness of our program at teaching. We are also editing the bacterial interactions lab to fit a Course Source template so that it can be submitted for publication to that portal and implemented at other universities.

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