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Essay

Learning the Science of Research, Learning the Art of Teaching: Planning Backwards in a College Genetics Course

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Abstract

This paper examines how to incorporate 'backward planning' in a college-level genetics course at a large university in the southwestern part of the United States. The authors discuss how teaching was a limited part of their graduate education, but yet became an important, and very enjoyable part of their experiences as university academics. The authors argue that using backward design as a planning method can alter science education at the college-level, and that scholars in the sciences can use research in education to become better teachers and researchers.

Keywords: backwards design; undergraduate education; genetics lecture

Introduction

Learning how to teach college-level science in the United States can resemble a trial by fire. Graduate students may serve as a Teaching Assistant (TA) for academic members of staff or may not be required to teach at all. TA duties can include holding office hours or recitations to tutor undergraduate students in a particular class, grading assignments and/ or exams for academics, or teaching a small lab section for introductory science courses. They most often do not include in-depth discussions of pedagogy, learning styles, outlining course objectives, and the like. For example, as a graduate student in the biomedical sciences at a large medical school with no undergraduate population, I spent very little time thinking about teaching. My graduate education revolved around designing and interpreting research experiments and writing research grants. Needless to say, the importance of teaching, let alone developing strategies that would enable students to be successful in my college courses, was a hidden art that I learned to value as my professional career progressed.

My love for teaching and for science education occurred progressively. During my first academic in the autumn of 2000, I was given little guidance on how to develop a course, so I took what I considered to be the obvious route: pick a textbook and lecture directly from the material in the textbook. The problem with this approach, however, was that my students were not learning the material. My method of teaching could be characterised as the design by hope approach, which disseminates information and hopes that students internalie it. My recent foray into pedagogical literature provided me with an alternative approach, called the 'understanding by design' (Wiggins and McTighe, 2005; Allen and Tanner, 2007; Roth, 2007) method, which encourages teachers to plan the curriculum with the assessments in mind first. Doing so helps students engage with the material in authentic ways. Recent research in the field of education, specifically curriculum design has helped me to reconsider how I plan my science courses. The notion of 'backward planning' (Wiggins and McTighe, 2005; Allen and Tanner, 2007; Roth, 2007) provides me with a stronger structure to organise my Genetics course, and helps me to implement purposeful teaching.

Backward Planning

The basic tenet of backward planning is that teachers prepare the curriculum for their courses with the assessments in mind first. Instead of relying on the textbook to teach the course, backward planning relies on the teacher's knowledge of the material, her students, and the context to teach the course. To plan for the assessments in mind first encourages me to think about how students can represent what they have learnt in my course, or, to say in another way, how can students show what they know? It encourages me to use other assessment tools besides multiple-choice tests to see whether student grasp the material. In addition, it involves students in the teaching process. We get to discuss together the purpose of learning the material, why the material is important, and what are the best strategies for tackling the material. Thus, in addition to being able to memorise terms and content, students learn about how they understand and make sense of science. In short, they learn about learning.

My initial approaches to teaching science at the university committed the twin sins of curriculum design. These sins, as described by Wiggins and McTighe (2005) include the 'activity-oriented design' and the 'coverage' design. The first approach involves creating activities for students to do in the classroom, but neglects to connect the activities to a specific content focus. Instead of explaining how the activity helps students to engage with the material, the activity-oriented sin encourages students to complete activities for the sake of itself. Students are led to believe that the activity is the learning itself instead of the connection to a larger focus within the content. In short, the activity-oriented sin is 'Hands on without being minds-on'. The second twin-sin is coverage. Here students muscle through a text book, collecting and memorising a stack of factual material without a purpose or a focus. It is, in short, a whirlwind tour (Wiggins and McTighe, 2005) through the material. Backward planning, on the other hand, encourages teachers to begin with a more purposeful approach to the material by considering the desired results first, and moving backwards from there. It helps teachers to determine the 'priority learnings' that are important in the unit or course.

Backward Design occurs in three states:

- **Stage 1: Identify Desired Results**
  What should students understand and know how to do at the end of the unit/course? What are our priorities regarding content? What standards need to be met?
- **Stage 2: Acceptable Evidence**
  How will students show what they know? What is acceptable evidence for students to show that they have met the desired goals?
- **Stage 3: Plan learning experiences and instruction**
  What knowledge and skills will students need to be successful on this unit/course? What needs to be taught and what are the best ways to teach it? What additional resources may I use to teach this material?

Focusing on the desired results first requires me to think about how students can demonstrate their understanding of science, meaning what are the pieces of evidence that students can use to show that they understand the content. This allows me to expand my assessment approaches in science and differentiate my instruction to meet the diverse needs of students. Relying on textbooks and exams from textbook publishers exemplifies the untenable 'one-size fits all' method of science teaching. Moreover, it allows me to move away from the spray and stay approach to teaching, to focus on how students can authentically illustrate their learning. Finally, it helps me to shift from focusing on my teaching (lectures) to concentrating on my students' understanding and learning. A important aspect to designing performance assessments is providing students with several opportunities and many different ways to show that they have an understanding of the material. These can include quizzes, exams, debates, poster-board presentations, portfolios, art work, drama/performance/role-playing, personifying concepts, dance, scenarios, and writing (e.g. poetry, journals, letters, essays) assignments. Performance assessments need to be both formative (on-going) and summative (at the conclusion as a culminating experience).

Table 1 *Explanation of GRASPS (adapted from Wiggins and McTighe, 2005, pp. 158-159)*

Element of GRASPS	**Explanation**	**Components**	**Example from Wiggins and McTighe**	**Example from Sophomore Genetics**
Goal	The action that students will take in the scenario	Your task is… The goal is to… The problem or challenge… The obstacles to overcome are…	As a scientist with a consumer research group, your task is to design an experiment to determine which of four brands of detergent will most effectively remove three different types of stains on cotton fabric.	As a student in the genetics research lab, you will be able to design an experiment to test whether or not a compound is mutagenic (Marshall, 2007)
Role	Who the students are in the scenario	You are… You have been asked to… Your job is…	You are a scientist	You are a genetics researcher testing a mutagenic compound (Marshall, 2007)
Audience	With whom the students are most concern; To whom are they addressing	Your clients are… The target audience is … You need to convince…	Your target audience is the testing department for *Consumer Research* magazine	You will develop this PowerPoint presentation to educate your fellow students as to the toxicity and mutagenicity of your compound (Marshall, 2007)
Situation	The challenge and the details of the context	The context you find yourself in is The challenge involves dealing with	You have a two-part challenge: (1) to develop an experimental design for isolating the key variables, and (2) to clearly communicate the procedures so that the staff of the testing department can conduct the experiment to determine which cleaner is most effective for each type of stain.	You will propose an experimental design and develop a hypothesis about a compound you bring from home (Marshall, 2007)
Product, Performance, and Purpose	What will students produce during the activity	You will create a _____ in order ___ You need to develop ______ so that _____	You need to develop a written experimental procedure (following the given format) outlining the steps in sequence. You may include an outline or graphic format to accompany the written descriptions.	You will keep a lab notebook detailing your hypothesis, experimental methods, results and conclusions so that you can repeat the experiments at a later time
Standards and Criteria for Success	How will this assignment be assessed?	Your performance needs to ____ Your work will be judged by ____ Your product must meet the following standards ____	Your experimental design needs to follow the criteria for good design accurately and completely; appropriately isolate the key variables; include a clear and accurate written description of the procedure (an outline or graphic to assist the testers is optional); and enable the testing department staff to determine which cleaner is most effective for each type of stain.	Your lab report will be understandable to someone who has not taken this lab. They should be able to identify your hypothesis, and follow your reasoning to your conclusions. The materials and methods should be written so that they can repeat the experiment without any additional reading on their part.

Wiggins and McTighe (2005) purport, however, that one core assessment should be based on GRASPS, and acronym for Goal, Role, Audience, Situation, Performance, Standards. An important part of GRASPS is to place students in a real-world scenario where they produce artefacts that reflect both the content of the course and what they may need to produce in an authentic setting. Table 1 above gives a further explanation of GRASPS.

Backward Design in a Genetics Course

Students typically take multiple-choice tests in science classes. They typically cram for it, take it, and then forget it. It is the move 'em in, move 'em out strategy for teaching and learning.

Table 2 *Six Facets of Understanding (adapted from Wiggins and McTighe, 2005) with examples in a Genetics course*

Facet of Understanding	Description	Evidence in Planning
Explanation	Why is this so? How does this work?	Why does the offspring look this way? Why don't the offspring always look like their parents?
Interpretation	What does it mean? Why does it matter?	How are traits inherited? Why does inheritance matter? Why is understanding inheritance important? Is Biology destiny?
Application	How can I apply this? How do I adjust to meet the situation?	How can we determine how traits are revealed in Drosophila? How do I design an experiment to determine how traits are inherited? How can I determine how a DNA sequence relates to a trait that I can see?
Perspective	From whose point of view? What are the strengths and limits of the idea?	How does genetics neglect to deal with environment influences on choices that human beings make? What are the benefits of knowing your genetic history? How is genetics viewed differently by doctors, lay people, anthropology, historians, criminologists, genealogists, politicians, bio-scientists, and ethicists?
Empathy	What do I need to experience if I am to understand? What was the author feeling, seeing, and trying to make me feel and see?	What experiences do I have personally that may influence my hypothesis and interpretation of the results? What can we learn from my experiments about the changes that occur after genetic mutations? How much should researchers (broadly defined) take into consideration the feelings of individuals in their research? What are the ethical responsibilities of individuals who use genetics?
Self-Knowledge	How does who I am shape my views? What are the limits of my understanding?	How does what I understand about genetics shape my views about human inheritance, including, genetic testing, personalized medicine, race, and eugenics? What are the limits of my understanding of genetics? How has my understanding of myself changed as a result of my knowledge of genetics? How does learning about genetics influence my understanding of my own personal history?

Planning backwards takes a different approach. Understanding, according to Wiggins and McTighe (2005) involves the ability to transfer knowledge to new and at times confusing situations. In addition, it involves "...the capacity to take what we know and use it creatively, flexibly, fluently, in different settings or problems, on our own." It does not just include plugging in the same information, but being able to use it in a different way in a new situation. They contend that understanding is a six-sided view of concern. To possess a strong understanding of the material, students need to be able to explain, interpret, apply, have perspective, empathise, and have self-knowledge of and from the material. The chart above provides a summary of their view of understanding. As we can see, understanding the material is more than simply memorising the content. Instead, it requires that students think deeply about it, consider its larger implications within the field, and how it applies to themselves and their lives.

An important way to help students to transfer knowledge and understand it is to develop essential questions and enduring understandings. Prior to starting a unit/course, the teacher needs to state and explain the performance assessments, the essential questions and the enduring understandings for the unit/course. Doing so, helps students to focus on the learning objectives for the unit/course, guides their reading, and illustrates for them the larger goals for the course. In short, they focus the teaching and learning on their understanding, and provide everyone with the same roadmap, thus, giving students and teachers purposeful teaching and learning experiences.

Table 3. Examples of a) Enduring Understandings and b) Essential Questions in Genetics Course.

(a)

Topical Enduring Understandings	Overarching Enduring Understandings
In many instances genotype directly dictates phenotype.	Understanding genetics can improve the human condition.
The ultimate reason for sexual reproduction is to enhance genetic variability in the offspring.	Misusing individual's genetic information can lead to destructive and sometimes violent consequences.
Concepts of dominant and recessive alleles.	Inheritance of traits in humans is affected by more than just genotype.
Somatic cells are diploid; gametes are haploid; the fusion of two haploid gametes leads to the regeneration of a diploid offspring.	All living things utilize the same genetic code (DNA codons for amino acids are the same across the 3 domains).

(b)

Topical Essential Questions	Overarching Essential Questions
How are genotype and phenotype related?	What are consequences of seeing biology as destiny?
What is the law of independent assortment?	How can we use genetic information to improve human health and human relationships?
How do chromosomes line up in metaphase I of meiosis?	What are the ethical responsibilities of individuals who study and use genetics?
What is the definition of an allele?	How can human genetic information be misused and how we can be ensure this won't happen?

Essential questions and enduring understandings drive the unit/course along with the performance assessments. They help students focus their learning during the course. There are two types of essential questions and enduring understandings, each of which are important to the course design (see Table 3). Topical essential questions are ones that pertain to the specific content. They help students think critically about it. Overarching essential questions, on the other hand, are ones that pose more general, philosophical questions about the content that may not have easy answers to. They are, in short, questions that people argue about outside of university. The content is used as evidence to present answers to these debatable questions. Enduring understandings are similar. Topical enduring understandings pertain to the specific content, while overarching enduring understandings are conclusions based on logic and evidence. They are not necessarily the main ideas of a subject, but what conclusions can we draw from the subject based on several ideas. They require students to synthesise material to make reasonable explanations and judgments.

Science is not a list of facts to memorise; instead it is a way of knowing and thinking about the world around us (National Research Council, 2003). For too long we have taught students that cells work one way and DNA does one thing, only to be shown later on through experimentation that in fact, cell processes often do not work the way we think (the most striking example in recent biology is siRNA and gene expression [Kuldell, 2006]). Backwards design is potentially an effective approach in science education for college students, as it allows them (students) to be taught scientific skills, concepts and problem-solving strategies, instead of a series of soon outdated facts (National Research Council, 2003; Allen and Tanner, 2007). Topical essential questions and enduring understandings can serve as a framework for a science unit in a college classroom. Incorporating these curriculum components in a unit frames the assessments and encourages students to think about issues related to science, and apply the information in the textbook.

A good starting point for backwards design in a science course is the series of questions discussed above. The instructor can ask, what should my students know (lower and higher order thinking) when they finish this unit/module In addition, science instructors can ask themselves at the beginning of the planning stage, what should my students be able to do? Should they be able to interpret data? Should they be able to use mathematics to analyse a biological process? Should they be able to design and interpret an experiment? Should they be able to write a lab report? Develop a presentation on their experiments? Present on others' work? If these are the outcomes, how will students show what they know? What other performance assessments (e.g. drama, role-playing, art) could use to show what they know? Finally, the professor needs to ask him/herself questions such as, What skills and concepts do students need to know in order to be successful on this assignment? What strategies (e.g. group work, role playing, individual presentations) could I use to help my students learn these skills and concepts? What real-world events (e.g. popular culture, news events, sports) could I use to help my students understand these skills and concepts? Answers to these questions will reshape a science unit, and could alter how academics approach their teaching.

Additionally, appropriate assessments must be developed (Wiggins and McTighe, 2005; Handelsman *et al*., 2006; Anderson, 2007; Schonborn and Anderson, 2008). This is often the most difficult part of my task (see Table 4). How can I develop an assessment that effectively gauges what I want the student to learn? Multiple choice exams are easy to mark, but do they test what you want the students to understand or be able to do? Essay tests are harder to grade, but will allow a more complete coverage of the understanding of the concept or content. Continuous assessment such as learner response systems (clickers) or frequent quizzing can yield information more quickly about the topics in a multiple choice or short answer format on which students are having problems but can be a formidable challenge in terms of time commitment (Anderson, 2007). The most effective method of assessment is to implement many different types of tools using the GRASP model (Table 1) (Wiggins and McTighe, 2005). Schoborn and Anderson (2008) describe succinctly multiple methods for incorporating mindful assessment into biological courses. There are many active-learning methods for college level science courses. These include: problem based learning, case studies, and concept maps (for example, Handelsman, *et al*., 2006; Allen and Tanner, 2003; DiCarlo, 2006). Backward design allows me to incorporate active learning strategies in my classes.

Using backward design in my teaching has allowed me the freedom to use the textbook as a resource and not as a driver of my course. To develop my course goals, I have determined the skills that students need to know when they finish my course and the foundational understanding they need to have to move forward in the major and in their careers; some examples are outlined in Table 3. I have been able to move away from simple multiple choice testing to more advanced assessment modalities including pre and post testing, problem solving, short answer, and mastery learning (see Table 4). I also added much more ongoing and formative assessment in my sophomore-level[1] genetics course using online quizzing so I can gauge more quickly trouble spots to design an impromptu activity in class to cover the concept. In addition I am developing, assessing, and publishing a series of labs for a genetics course. Finally, I am going to implement a summative genetics concept inventory (Garvin-Doxas, et al. 2007; Bowling *et al*. 2008; Smith *et al*. 2008) to determine if the students are learning and retaining key concepts in genetics.

Table 4 *Examples of Performance Assessments in Genetics Course*

Performance Assessments	Explanation	Example in Unit
Frontloading Assessments	Helps connect students to material; Activate prior knowledge/ prior experiences; You want to connect students to the material, and you want to begin thinking about the important issues of the unit	Worksheets and lab exercise on inheritance, focusing on Punnett squares and pedigree analysis.
Formative Assessments	Assessments that are on-going; they continually check to make sure that students are understanding the basic information, and are engaging with the material in authentic, personal ways.	Quizzes; Answering definition questions, problem-solving questions, and higher-order questions.
Authentic Assessments	Art; Drama; Scenarios, GRASPS; They help students “transfer” the information to other arenas.	Concept Mapping; Collages of Central Dogma of Molecular Biology; case study in which student role plays a physician or genetic counselor in which they have to explain why a couple’s child has a genetic disorder such as Tay Sachs (autosomal recessive disorder) or Down syndrome (trisomy X) and how human genetics plays a role in this genetic disorder.
Summative Assessments	An overall assessment of how well students learned the material in the entire unit/ course. Each assessment above should help students successfully complete the summative assessment(s).	Final Exam; Multiple-choice exam; includes each of the assessments above, including scenarios; encouraging students to regurgitate and transfer knowledge. Final exam, genetics concept inventory, lab report, PowerPoint presentations, lab notebook (full semester).

Average marks in the class stay approximately the same while I incorporate more higher order questions asked on exam. Over the years, the student evaluations of the class have become

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more positive. In addition, personal satisfaction and interest in teaching has increased when I learn with the students. This has become the best part of my job. Even though I earned a Ph.D. in biology to be a researcher, my exploration into the research on curriculum design has shown me that teaching can cease being an annoyance and instead be an exploration of an art.

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