Animal development in the secondary classroom: linking basic science to livestock production

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Abstract

The field of life sciences encompasses a myriad of disciplines that collectively provide insight toward the intrinsic framework of life. Developmental physiology is one of these disciplines that can describe the origins of life at the molecular, cellular, tissue, and organismal level. However, organismal development is a continual process that transcends conception and progresses throughout the lifetime of an organism. In this Illumination, we discuss opportunities that secondary-level life science educators have when teaching developmental physiology through an agricultural lens. Specifically, we propose teaching about the origins of meat and milk, as a nontraditional approach for introducing developmental physiology to students. To justify this notion, we explore how novel research in livestock production focuses on meeting food demands imposed by our growing global population. In addition, we link these concepts to commonly employed standards in secondary-level science classrooms across the United States. In conclusion, the science of livestock production provides a window of opportunity for secondary-level physiology instructors to teach developmental physiology in a form that can readily adhere to institutionally employed standards.

animal development; physiology education; secondary/high school

INTRODUCTION

The field of life sciences encompasses a wide range of disciplines which span various levels of basic and applied detail. Almost equally as varied is the form in which these disciplines are taught (1). For secondary educators in the physiological sciences, common classroom objectives include enhanced program quality, student inquiry, and continued experiential learning, preferably through a constructivist-based approach (2). Therefore, it becomes imperative for educators in this discipline to consider novel methods to soundly teach the different aspects of physiological science in a holistic manner.

The subject of developmental physiology spans a gamut of foci ranging from organismal conception to end-of-life biology. Teaching developmental physiology requires an appreciation of the intrinsic dynamic change encompassed by the discipline. In fact, it is suggested that this inherent nature of developmental physiology requires four-dimensional cognition, potentially setting it apart from other disciplines in the realm of life sciences (3). Particularly, this is due to the transformative nature of variables considered in such a subject’s content.

Given the fact that present estimates calculate the world’s population to reach just under 10 billion by the year 2050 (4), physiology educators should teach with this reality in mind. For the past several decades, advances in both science and agriculture have paved the way toward ensuring food security in our planet, a matter that affects us all (5).

Therefore, we propose the teaching of developmental physiology at the secondary level through using livestock production as one, of many, potential alternatives for engaging students in the applied aspects of developmental physiology.

LIVESTOCK DEVELOPMENT AND THE SECONDARY CLASSROOM

Material taught in a developmental physiology course can be considered both a fact and a concept, depending on the way an instructor formulates a course structure (6). However, when taught through an agricultural lens, emphasis can be placed on teaching developmental physiology in a form that is readily implementable to have a global impact. In animal production, producers understand that livestock growth and development determine various outcomes in final marketable products, such as meat and milk (Fig. 1). Indeed, such a perspective could be useful in the classroom, as prior research has shown amplified student-engagement in secondary-level biology classes through the use of applied agricultural examples (7).

In 2017, the United States was home to 8,471 school-based agriculture programs (8). However, by no means should science educators independent of school-based agriculture programs omit agricultural-related examples from their courses. In Table 1, we provide a list of select life science performance expectations from the high school Next Generation Science
Standards (9). Throughout the remainder of this paper, we use these standards as examples in justifying the integration of livestock development into the secondary classroom.

APPLIED CONCEPTS IN DEVELOPMENTAL PHYSIOLOGY

While growth generally refers to an increase in size, development tends to refer to an increase in complexity. Exclusivity, however, does not hold true for these concepts as each is just as integrated to the other in physiological reality. Fertilization of an oocyte results in a zygote. Almost immediately after this event, numerous known and unknown metabolic pathways trigger the transformation of a zygote into an embryo. During this time, various endogenous and exogenous factors regulate continued embryonic growth and development. These changes are anything but static, as still-framed representations of this dynamic physiology are only further influenced by variables such as time, the environment, and species type. For example, the nutrition of a gestating farm animal has vast implications on the short- and long-term development of her offspring (10). Meanwhile, in the postnatal animal, dynamic growth and development continue on a daily basis. Similarly, endogenous and exogenous factors play critical roles in orchestrating this complex physiology. Through this life-cycle, secondary-level students could be guided through formative and summative strategies that bridge the hierarchical connections between physiological biochemistry and agriculture (11).

Considering the Origins of Meat

One area of focus in agriculture is that of meat production. The amount of muscle on an animal determines the amount of potential meat-product to be derived, while the amount and location of adipose can enhance the flavor and juiciness of meat.

Skeletal muscle development begins at embryonic stages when mesenchymal stem cells undergo determination to form myoblasts (12), which can subsequently differentiate and fuse to form muscle fibers (13). Collectively, these processes can be termed as myogenesis. Meanwhile, the formation of adipose tissue similarly begins with the same mesenchymal cell precursors of skeletal muscle (14). However, these cells commit to an adipogenic lineage due to epigenetic activation that results in preadipocytes. The differentiation of preadipocytes results in mature adipocytes, thus completing adipogenesis. Together, these concepts allow educators to illustrate in the classroom how complex tissues may derive from similar cells, which differentiate into entirely different tissue types (HS-LS1-4; Table 1).

To take it one step further, educators can extrapolate the underlying mechanisms that distinguish the development of these specific tissues. Considering the differentiation of preadipocytes to adipocytes, a transcription factor named peroxisome proliferator-activated receptor gamma (PPARγ) is engaged in the process of adipogenesis.

Table 1. Select Next Generation Science Standards

| Performance Item | Performance Expectation |
|------------------|-------------------------|
| HS-LS1-1         | Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins, which carry out the essential functions of life through systems of specialized cells. |
| HS-LS1-2         | Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. |
| HS-LS1-3         | Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis. |
| HS-LS1-4         | Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms. |
| HS-LS3-1         | Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. |
| HS-LS3-2         | Make and defend a claim based on evidence that inheritable genetic variations may result from 1) new genetic combinations through meiosis, 2) viable errors occurring during replication, and/or 3) mutations caused by environmental factors. |
| HS-LS4-1         | Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. |

See Next Generation Science Standards in Ref. 9.
necessary to activate numerous genes that enable lipid accumulation and adipocyte morphology (HS-LS1-1; HS-LS3-1; Table 1). Without PPARγ, the genes that code for the enzymes that promote preadipocyte differentiation will not be expressed (HS-LS3-1; Table 1). For livestock producers, this is crucial as the development of intramuscular adipose tissue bestows a desirable flavor in meat products and thus enhances product value. Herein, we see an opportunity for students to develop a model that explains the hierarchical nature of tissue physiology (15) in multicellular organisms due to the molecular action of a molecule like PPARγ (HS-LS1-2; Table 1) and the background behind breeding programs aimed at enhancing livestock production (HS-LS3-2; Table 1). Furthermore, this same example demonstrates how a molecule like PPARγ can allow the code of DNA to produce proteins necessary for differentiating preadipocytes (HS-LS1-1; Table 1).

Navigating even deeper into the development of adipose tissue establishes the comparative perspective that adipogenesis occurs throughout embryonic, fetal, and postnatal development and through different anatomical locations: visceral adipose, subcutaneous adipose, intermuscular adipose, and intramuscular adipose (HS-LS4-1; Table 1). Novel advances in research have demonstrated that producers can employ specific management tactics to promote the growth and development of desired fat (intramuscular adipose) in their livestock (10). This concept is called “fetal programming” and describes various windows to impact embryonic/fetal growth and development over time, such as through a nutritional intervention (HS-LS1-2; Table 1) and represents the inherent intricacy that developmental physiology educators must realize when teaching their classes (3); developmental physiology is a continuous process that cannot comprehensively be modeled as a static, deterministic, or empirical phenomenon.

**Considering the Origins of Milk**

Unique to the phylogenetic class Mammalia is the presence of mammary glands (HS-LS4-1; Table 1). The widely accepted contemporary consensus on the evolutionary origins of the mammary gland propose apocrine-like sweat glands in being precursory to modern-day mammary structures (16). In mammalian females, these structures are responsible for synthesizing and providing a highly nutritious aliment to both precocial and altricial neonates. The mechanisms leading up to these functional glands involve dynamic allometric and isometric developmental patterns that, to this day, are not entirely clear (17). Nonetheless, research in this area progresses intensively because of its implications in the areas of agricultural production and oncological health (18, 19).

A comparative analysis of the morphology in a mature mammary gland depicts similarities among mammalian species. Classically, the milk-producing epithelial tissue found in a mammary gland is referred to as alveolar tissue. This tissue is composed of functional cellular units referred to as mammary alveolar cells. Conglomeration of these cells into a spherical shape result in an alveolus. Groups of alveoli make up lobules while groups of these lobules are then anatomically bunched into lobes. The product of these lobes, milk, drains externally through an organized ductal system into the gland cistern. In cattle, milk can be stored here as an intermittent reservoir in anticipation for quick expulsion through the teat. Several cells play critical roles in the development and function of a mature mammary gland (HS-LS1-2; HS-LS1-4; Table 1). Alveolar cells are primarily responsible for the synthesis and secretion of milk. Through neuroendocrine signaling, myoepithelial cells surrounding the alveolar cells contract, resulting in the secretion of milk into ducts composed of luminal epithelial cells. Altogether, these cells make up the internal epithelial network of mammary epithelial tissue. To support this invading epithelial system, connective tissue, also called the mammary stroma, which includes fibroblasts and adipocytes, provides a platform through which mammary epithelial cells can proliferate. In fact, a majority of epithelial proliferation and developmental morphogenesis occurs in response to extrinsic factors derived from this stromal environment (20). While the bovine mammary gland begins to undergo allometric development during pre- and postpubertal stages, most mammary development primarily occurs throughout pregnancy and epitomizes upon the onset of lactation. By providing students with this anatomical perspective of the mammary gland, they can be exposed spatial visualization of tissue development (21), which can be critical for learning (15, 22).

Subsequently, instructors can use the modern-day dairy cow as a conceptual model to exercise the fourth-dimensional

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**Figure 2.** Relative energy transformations associated with lactation. Modified from Ref. 25.
cognition necessary to comprehend developmental physiology (3). Specifically, this can be done by introducing students to the macroscopic tissue development involved in both homeostatic and homeorhetic endeavors of a lactating dairy cow (23), as associated with mammary gland demands (HS-LS1-3; Table 1). Briefly, homeostasis describes the continuation that physiological systems undergo to maintain constancy within organisms. On the contrary, homeorhesis describes the change in the metabolism of physiological systems that takes place in order for new priorities imposed by a new or upcoming physiological state. As a matter of fact, this transition from systemic homeostasis to homeorhetic homeostasis is so profound in the modern-day dairy cow beginning to lactate that she has been demoted by lead researchers in the discipline to being simply an “appendage to the mammary gland,” due to the metabolic demands and prowess of the gland (24). These system changes can be described by the relative changes in milk production, feed intake, and body weight that are experienced by lactating dairy cattle (Fig. 2).

Parturition marks the onset of lactation in dairy cattle. As demonstrated by Fig. 2, for the first 2 mo in lactation, the dairy cow experiences an energy balance challenge, reflected by a drop in bodyweight. This is a result of the homeorhetic changes favoring increased milk production in addition to lagging compensatory feed intake. During this time, tissue development in the cow prioritizes the production of milk. A major change experienced in the cow during this time, as reflected by her weight loss, is the hypotrophy of adipocytes. This is because lipolysis mobilizes adipocyte stores to provide the energetic demands of the cow and to supply lipid substrates needed by the mammary gland. Additional developmental changes experienced by a cow during this time include an increase in the size of the digestive tract and the liver, to accommodate increased nutrient absorption and metabolism, respectively (26). After ~8 wk, lactation peaks and feed intake begin to compensate for previous weight loss. This period of time also coincides with the breeding time of most commercial cattle (27) and presents another opportunity to showcase developmental physiology to students through a breeding perspective (HS-LS3-1; HS-LS3-2; Table 1). Modern-day multiparous dairy cattle can average a first-service conception rate with a range as low as 30–35% (28). Novel research in this area explores the failure of the high-producing cow to promote a suitable environment for her developing embryos, especially since most reproductive losses in dairy cattle can occur during early embryonic development (29–31). This reality demonstrates the myriad of development that takes place at any given point in the commercial dairy cow. While lactating cows are pumping out an average of 34 liters of milk per day (32), their bodies undergo vast development to promote these endeavors in addition to promoting the development of future offspring (HS-LS3-1; Table 1).

After a dairy industry standard 305-day lactation year, the mammary gland is allowed to involute for around 60 days. During this time, vast remodeling of mammary tissue is necessary for the new forthcoming lactation cycle. Here, the gestating dairy cow experiences the regression of old mammary tissue and the development of new mammary tissue, while a developing conceptus prepares for parturition (HS-LS1-2; Table 1; Fig. 2). As with meat production, the development of the mammary gland across the lactation cycle is subject to influence by many factors, including nutritional regimens (33, 34).

Altogether, mammary physiology reflects another worthwhile classroom opportunity to showcase the dynamic interplay between development aimed at maintaining tissue function, via homeostasis, and development aimed at achieving a new physiological state, via homeorhesis (23). Furthermore, this perspective introduces students to the reality that milk, like meat, is not just a substance found in stores, it is a substance that owes its origins to vast tissue development that continues throughout a bovine lifetime.

## MOVING FORWARD

In 2002, the Nobel Laureate, Dr. Norman E. Borlaug (1914–2009), argued that due to scientific advances in the 20th century, and centuries prior, food production was able to keep ahead of population demands. However, given the increasing rate of population growth in the 21st century, it becomes worrisome to consider the realities imposed by this change; hence, Dr. Borlaug dubbed the solution to increased food demands as “The Miracle Ahead” (35). If we are to truly perform a “miracle” for meeting food demands levied by our inevitable future, we can start by considering the way we educate the next generation of scientists. Ideally, educators should provide the spark necessary to encourage their students to pursue a career revolving around the integration of science and agriculture. Thus secondary-level life science educators are encouraged to adopt applied examples into their classrooms to efficaciously teach multifaceted subjects, such as developmental physiology.

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## DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

## AUTHOR CONTRIBUTIONS

N.A.G. conceived and designed research; N.A.G. prepared figures; N.A.G. and M.D. drafted manuscript; N.A.G. and M.D. edited and revised manuscript; N.A.G. and M.D. approved final version of manuscript.

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