At the Intersection of Historicity and Epistemology

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As of 2015, the enamel knot is widely recognized as the morphogenetic control center of the tooth; that is, it directs and shapes the outgrowth of the developing tooth. The enamel knot thus currently plays a role in explaining how teeth gain their characteristic forms. During the century since it was discovered, it has moved from an explanatory role for tooth development to a marginalized and even contested entity throughout a majority of the 20th century, and now is a central scientific object within developmental evolution tooth research. How did this happen? That is, how did a scientific object that is central to a modern scientific paradigm, such as the enamel knot, undergo such upheaval? And, what does this story tell us about the way in which scientific objects, as actors, play a role in their own history? This paper combines historical and philosophical perspectives to highlight the historical contingency of a scientific object and the dynamic tension between a scientific object and its epistemic setting.

In this paper, I dissect the relationship between a scientific object (the enamel knot) and five historical epistemic settings, i.e. the theoretical and methodological commitments of the researchers in which the scientific object was understood. In order to characterize the epistemic setting of each historical case, I ask two simple questions. First, what do the researchers take development to be? And, second, what was the process by which they characterized development? The five historical cases are:

1. Hans Ahrens, 1913. Ahrens was concerned with gross morphology; through depicting the changing dimensions of tissues and structures, mediated by his creation of wax models, Ahrens discovered the enamel knot and understood it to play an active role in shaping the tooth.

2. Erwin Reichenbach, 1926/1928. Reichenbach adopted an understanding of tooth development mediated by histology and the internal biomechanics of tissues. Tooth development and morphogenesis to Reichenbach were best explained through describing the forces and active properties of the developing tissues, i.e. cell populations that were dividing and moving. The enamel knot held no explanatory role in tooth development.

3. Erich Blechschmidt, 1953. Blechshmidt's concept of development hinged on his "theory of biodynamics", in which anatomy and morphogenesis had to be explained by focusing on the movement of elements, whether they be molecular, cellular, or otherwise. The enamel knot held no explanatory role in tooth development.

4. Tadao Kirino and Tetuo Nozue, 1971/1973. Development for Kirino and Nozue is understood through chemical factors signaling for the expansion and outgrowth of tissues. The enamel knot is posited as a signaling center, but no one followed up on this research.

5. Jukka Jernvall, 1994. Jernvall began to uncover the genetic signalling properties of the enamel knot. His theory of development understood morphogenesis as the interaction of

physical phenomena, such as differential cell proliferation and cell movement, in combination with genetic signaling. The enamel knot becomes the morphogenetic control center of the tooth mediating morphogenesis of the surrounding cells and tissues.

As I move through and unpack the epistemic setting of each historical case, I also highlight the ways in which the properties of the enamel knot interacted with each of these settings. There are six properties of the enamel knot that have intersected with this scientific object's epistemic settings in interesting ways:

1. Position: The enamel knot resides within the enamel epithelium, in close proximity to the dental mesenchyme.
2. Inert: The cells that compose the enamel knot do not divide.
3. Static: The cells that make up the enamel knot form a solid, dense ball which does not move.
4. Pre-patterns: The non-dividing cells of the enamel knot direct the tooth to form cusps and then it disbands before the cusps actually form.
5. Signaling: The enamel knot signals to surrounding cells to proliferate.
6. Transient: The enamel knot appears and quickly disappears during early stages of tooth development.

We will see as we move through the cases that the way each researcher characterized the developmental process (particularly the way that they understood the process of morphogenesis), and the methods that they used to interrogate tooth development, colored the way they interpreted their data and understood the properties of the enamel knot. This in turn affected the enamel knot's role in explaining tooth development and its status as a scientific object.

By telling the history of the enamel knot from the role of the object itself within the scientific process, that is, how the object interacts with the methods and theories of an epistemic setting, I demonstrate that the history of scientific objects is governed by the ways in which their properties interact with the epistemic commitments of the experimental systems that house them. This is a story about how the properties of a scientific object are an integral part of that object's uptake and role within science. This is also a story about how theories of development, particularly morphogenesis, shifted throughout the 20th century in important ways. In this light, this paper begins to address the history of developmental biology and highlights ways of understanding and framing development that are alternative to the molecularized narratives that have dominated the history of this topic and time period.