Building a Learning Progression for Chromosome Segregation Using Phenomenographic Variation Theory

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Abstract: Chromosome segregation is a critical yet challenging concept in genetics. Most studies on how students learn genetics has focused on the K-12 level. Here, we describe the process of building a learning progression for chromosome segregation at the undergraduate level using variation theory from phenomenography. A major finding is that students demonstrate increasing sophistication in connecting the different modes of representation of chromosome segregation used in instruction.

Rationale

Chromosome segregation is a critical phenomenon in cell division and is one of the most important yet difficult concepts for students in genetics (e.g. Kindfield, 1994). Chromosome segregation provides the mechanistic explanation for inheritance and Mendel's laws, as well as a means to understand complex genetic phenomena, including recombination or crossing-over, nondisjunction, and chromosome rearrangements.

Despite much instructional effort, students have difficulty grasping the phenomenon of chromosome segregation, as reflected in their performances in diagnostic tests (Smith, Wood, & Knight, 2008). In particular, many students cannot depict the proper structure of chromosomes in mitosis and meiosis, are unable to position gene alleles in their correct positions on chromosomes, and have trouble explaining the causal relationships between errors in chromosome segregation and the outcomes of meiosis (Smith & Knight, 2012).

The central question is *how* students conceptualize the process of chromosome segregation. Only with this knowledge could we identify learning obstacles and design effective instructional interventions accordingly. Since most studies on students' learning of genetics have been focused on the K-12 level (e.g. Ducan, Rogat & Yarden, 2009), there is much need to unpack how undergraduate students understand chromosome segregation, especially the more advanced aspects of this phenomenon. Therefore, we focused our initial effort on recombination, a critical aspect of chromosome segregation in the undergraduate genetics curriculum.

Theoretical Approach

This study is designed to explore how students conceptualize the process of chromosome segregation and to identify the obstacles that prevent them from learning this phenomenon effectively. As the study is exploratory in nature, the research question is left intentionally broad to capture students' wide range of conceptions.

We used variation theory from phenomenography as a theoretical framework. Phenomenography, a qualitative research methodology, investigates the various ways that people experience or conceptualize a phenomenon (Marton 1981). Variation theory offers a theoretical lens to explore the possible variations in these experiences and the learning that result from these differences (Bussey, Orgill & Crippen, 2013). Variation theory posits that each phenomenon (i.e. chromosome segregation) has defined aspects (e.g. recombination), and for each aspect, there is a limited number of features that exhibit distinguishable variations among them. Learning occurs when the different features and their variations are integrated into a coherent whole.

Variation theory can potentially be a useful theoretical framework for building learning progressions (e.g. Swarat, Light, Park & Drane, 2011). Learning progressions are descriptions of increasingly sophisticated ways of thinking about a phenomenon (National Research Council 2007). Essentially, learning progressions are conceptual pathways that students navigate as they develop understanding of a phenomenon. Defining learning progressions will provide the theoretical foundation to design instructional material that specifically targets transitions along these conceptual pathways.

Methodological Approach

The method of clinical interview was employed to explore students' conceptions of chromosome segregation. Clinical interviews help researchers gain insight into student mind by involving him or her in a concrete task, asking a "how did you do it?" or "why" question, and offering an immediate hypothesis making and testing regarding the student's response (Ginsberg, 1997). The flexibility and effectiveness of clinical interviews have led to its adoption in many studies of human cognition, the most relevant of which include the famous study of how experts and novices understand physics problems (Chi, Feltovich & Glaser, 1981).

We engaged students in interview tasks derived from their midterm exam questions that involve the phenomenon of chromosome segregation and, in particular, various aspects related to recombination. Students were asked to solve these problems, while being prompted to explain their problem-solving approaches and to illustrate their thought processes by drawing diagrams. An educational researcher trained in the research methodology led the interviews, and a content expert participated to ensure the quality of the interviews.

To capture the variety of student conceptions, we recruited students who demonstrated different levels of performance on the exam questions. That is, we included students who provided sophisticated answers representing multiple features of recombination, those who showed understanding of one or limited number of features, and those who performed poorly on the exam questions. This sampling method was chosen to increase the possibility that we witness the full variations among student conceptions.

Interviews were transcribed verbatim. Data analysis took a grounded approach, with iterative close reading of the transcripts and artifacts (i.e. student-drawn diagrams) to identify phenomenographic features of recombination and the variations among these features. Key aspects of chromosome segregation, especially in relation to recombination, were analyzed.

Findings and Conclusions

We report here the analysis of results from six interviews. A major finding is the disconnection among different features that students used to describe the phenomenon. Students had difficulty integrating the multiple features (i.e. modes of representation) of chromosome segregation and recombination employed in instruction. For example, Students with low performance on the exam typically recognized recombination of genetic material in offspring in one of three ways: conceptual (i.e. phenotypic differences from parents), mathematical (i.e. defined frequency from crosses), or symbolic (i.e. genotypic combinations of alleles). Students with increasing performance, and potentially increasing sophistication in understanding chromosome segregation, described the aspect in two or all three features.

We believe that these preliminary findings and our approach can shed light on possible ways to build a learning progression for chromosome segregation and recombination in particular. Ultimately, we anticipate that this study will yield an outcome space of different student conceptions of chromosome segregation. This outcome space will define a learning progression, including descriptions of varying levels of conceptions, key features that differentiate among the levels, and possible obstacles that prevent students from advancing toward more sophisticated understanding.

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