An Integrative Future Trend
of Problem-Solving Research in Genetics

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Recent research in genetics learning showed that students had inappropriate models of meiosis in their minds. These conception research studies are limited in the sense that they did not inform students' problem-solving success in genetics. Contemporary view suggests the inclusion of model-revising problems in problem-solving research in science education. Such problems require students to revise their existing basic models to fit into the anomalous data of the problem. In genetics, it is believed by researchers that both an understanding of the terms and a focus on the whole problem are crucial factors for problem-solving success. *In other words, the ability to apply concepts to problem-solving should be examined. The author thus suggests that future integrated trend of research in genetics should also incorparate the phenomenographic perspective to look at the approach to problem-solving of the problem solvers.*

The aim of tertiary education is to produce independent learners who can apply what they have learned to problem solving. A review of the literature of the curriculum of entry-level college science courses (biology included) showed that the aim was, very often, not achieved. The curricula mostly focus on "definition training" and "technique training" rather than a" mode of thought" or "conceptual framework" approach (Wartell, 1984).   For instance, many undergraduate science students have their science [courses] presented in such a mode that give rise to an almost total loss of *context-related conceptual appreciation* (Linder & Erickson, 1989; Linder, 1992). As a result, many students cannot develop new meaningful relationship with the new context that they are introduced to within the educational environment (Linder, 1993). Having received this kind of training in entry-level college science courses, most university students find it hard to understand Mendelian genetics This difficulty arises from the different assessment nature of Mendelian genetics.

Unlike introductory biology courses, most genetics course instructors base their assessment upon students' ability to solve problems correctly (Collins & Stewart, 1989). In mathematics and physics the problem-solving task often requires students to search for and complete the operations of an appropriate formula to calculate a solution which is a number. In genetics problems, however, there is no correct formula that will lead to a solution, and the solution is not always a number. The "rote memorization" strategy cannot be used to handle genetics problems. Therefore, it is important for genetics students to create a relationship with and to identify the *context*.

To investigate or predict students' success in solving genetics problems, both the conceptualization of meiosis and the process of problem-solving have to be investigated. The research tradition in higher education which takes on a relational perspective should be adopted (Ramsden, 1987). In this perspective, the teaching and the learning processes are conceptualized in a holistic way. It involves inquiry into and reflection on ways students learn specific subject matter in particular *contexts* (Ramsden, 1987). *Phenomenography is considered to be the appropriate perspective for it is concerned with "relations between the experiencing individuals and the experienced phenomena" (Marton, 1981). This perspective allows researchers not only to explore students' understanding of genetics concepts but also allow them to tap the entire problem-solving approaches of students. Earlier conception research in genetics learning only focused on conceptualizations of meiosis. Current suggestions to include model-revising problems in genetics problem-solving research by Stewart and Hafner (1994) open new scope for investigation. In order to understand students' application of their knowledge of meiosis to problems, researchers have to study their problem-solving approaches as well.*

Conception Research in Genetics

In the field of science education, there has been considerable research to investigate students' conceptualizations of scientific phenomena. Most conception research efforts have centred on physics, the most popular areas being force and motion, heat, electricity and kinematics concepts (speed, distance and time). For an example of force and motion, refer to Johansson, Marton and Svensson, 1985, Prosser and Millar, 1989; for heat see Rogan, 1988; for electricity see Danusso and Dupre, 1987; and for kinematics concepts see Walsh, Dall'Alba, Bowden, Martin, Marton, Masters, Ramsden and Stephanou (1993). A limited amount of work has been done in the biological field. Examples are found in conception research of meiosis (the process of cell division to form gametes).

Research on student conceptualization revealed a variety of students' inappropriate conceptualization (Brown, 1990; Peard, 1983; Smith, 1991; Stewart & Dale, 1989; Stewart, Hafner & Dale, 1990). Inappropriate conceptuali-zations are at variance with a concept which is a defined construct within a scientific discipline (Linder, 1989). For example, what appears to be a rather common students' inappropriate conceptualization concerns chromosome structure. Most students associated chromosome structure with chromosome number or ploidy (kindfield, 1992). Kindfield (1994) proceeded to suggest that individual's meiosis models were made up of not only their "inappropriate" models of chromosomes (i.e., the participating entities), but also "inappropriate" models of the process itself (i.e., the series of chromosome interactions or movements that define that process). Her recent study (Kindfield, 1994) extended the conception research of meioses by a more detailed microanalysis of the meiosis models utilized by novices (e.g., college genetics students) and experts (e.g., practicing geneticists) in a novel reasoning situation. Results of this study showed event-specific (i.e., replication, crossing over, alignment or segregation) misunderstandings and whole-process misunderstandings (i.e., knowledge about the process of meiosis). For an example of whole process misunderstanding, replication was considered to be part of process of meiosis but in fact it is not. Though this study provided an extensive understanding of experts' and novices' inappropriate conceptualizations of meiosis, it did not relate results to genetics problem-solving success.

Problem-Sovling Research in Genetics

Before the advocation of model revising problem, the genetics problem-solving research tradition could be described as mechanical for earlier research did not look deeply into the reasoning skills and the entire problem-solving process of learners as they were engaged in the problem-solving process. Most of these research were done within a Piagetian perspective or within an "expert-novice" perspective.

Piagetian research in the biological sciences has been extensive. The postulation of four rigid mental stages with corresponding age levels: sensori-motor, preoperations, concrete operations, and formal operations was *a popular interpretation of Piaget's cognitive developmental theory*. In the context of research in genetics, one approach had been to search for correlations between Piagetian operational levels and problem-solving success (Gipson & Abraham, 1985; Gipson, Abraham, & Renner, 1989; Walker, Hendrix, & Mertens, 1980; Walker, Mertens, & Hendrix, 1979). Most studies were done at the college or university level. Researchers in this school of thought postulated a more general correlation between formal reasoning and academic task performance success (Stewart & Hafner, 1994). Problem-solving success, in fact, could not be predicted by this simple, mechanical correlational task. Challenges to the Piagetian claims about genetics problem solving were made by Smith (1986) and Smith and Good (1983). In these studies, researchers compared the problem-solving performance of 11 novices (undergraduate science and nonscience majors who had just completed their first genetics course) and 9 experts (genetics graduate students and genetics faculty members) on a set of complex genetics problems with their performance on tasks which required formal operational reasoning. Results demonstrated that formal operational thought was insufficient to determine problem-solving success.

Researchers within the "expert-novice" perspective did not rely on Piagetian rigid age-specific models. They began by studying how high school students solved typical textbook problems. However, these problems only require students to reason from causes (know information on inheritance patterns, such as which variation of a trait is dominant) to effects (the prediction of offspring genotype or phenotype data) (Stewart, 1988; Stewart & Hafner, 1991). These problems

lend themselves to content-specific algorithms, which do not necessarily measure students' understanding of genetics (Stewart, 1988; Stewart & Dale, 1981, 1989). For example, students can use algorithms to predict the phenotypic ratio of offsprings in a genetics problem that involves monohybrid crossing of two heterozygous parents. They do not need to reason by the meiosis model in this type of cause-to-effect genetics problem.

Other researchers within the expert-novice perspective advance studies on genetics problem solving by using effect-to cause problems. These problems require solvers to reason from effects (phenotype data) to causes (the genotype of parents producing the phenotype data) (Stewart, 1988; Collins & Stewart, 1989; Stewart & Van Kirk, 1990). Unlike problem solving in cause-to-effect problems, mechanical, algorithmic procedures are not the only essentials for solving effect-to-cause problems. In other words, this type of problem is not immediately solvable through the application of algorithms. The solver has to decide which algorithms will be useful to check hypotheses concerning the inheritance (Stewart, 1988). Although effect-to cause problems require reasoning skills, problem-solvers can still apply a model (such as the simple dominance model) to solve these problems in which that particular model is operating. Under these circumstances, the concept of problem is depicted as model-using (Stewart & Hafner, 1991). This view of a problem in model-using research is similar to Nickles' (1981) positivist model where the focus has been on justifiication (bringing a model to bear on an empirical problem). Researchers working on model-using problems, therefore, failed to attend to the important issues of what students learn from solving problems, and how problem solving proceeds in situations where solvers' models are insufficient to solve problems (Stewart & Hafner, 1991).

Clement (1989) and Stewart and Hafner (1994) proposed that future problem-solving research should go beyond the model-using perspective. Preference should be given to model-revising problems. These type of problems usually consist of anomalous data that is inconsistent with the [learner's} existing model. The learner has to engage themselves in reasoning activities and to revise their existing model. The learner has to engage themselves in reasoning activities and to revise their existing model to account for anomalous data. In this way, the problem-solving

exercise is a more fruitful task. Data collected during the problem-solving process should have implications for teaching and learning.

If we acknowledge the importance of extending the concept of problem in genetics problem-solving research, the next question to ask is how researchers can determine students' success in this problem-solving process. Earlier conception research in meiosis did not provide the full solution to this question. In order to solve the problem, a solver has to create a relationship with and identify the problem context. Hence, understanding the content knowledge (technical genetics terms and symbols) and *applying them to the problem are both essential.*

Essential Elements In The Problem–Solving Process of Genetics

·Collins and Stewart (1989) proposed two areas that need to be addressed in the problem-solving process of genetics: content knowledge (meaning of genetics terms and symbols) and knowledge structure of genetics (problem class).

One source of difficulty for students to construct knowledge of genetics for problem solving might be the large amount of content knowledge that needs to be understood (Collins & Stewart, 1989). For example, the meanings of the terms-trait and variation, gene and allele, dominant and recessive, phenotype and genotype, and homozygous and heterozygous. Of course, we can always add terms to this list, depending on the problems introduced (e.g., genetics symbols, mutants). If problem-solvers have a clear definition of these terms, does it mean that they can definitely solve the genetics problems? The answer might be arbitrary. In order to solve genetics problems successfully, problem solvers have to understand the content knowlege initially. Next, they have to focus on the bigger picture of the whole problem. Finally, they have to integrate the content knowledge *and apply it* to the problem. All these are essential for problem solvers to identify the knowledge structure of genetics.

It is now clear that an identification of the knowledge structure (problem class) of a genetics problem is the key to problem-solving success. Collins and Stewart (1989) identified four different classes of genetics problem in

introductory genetics, namely simple dominance, codominance, multiple alleles and sex linkage. These four classes of problems might be further divided into two groups-inheritance pattern problems and modifier problems.

An inheritance pattern defines the basic relationship between genotypes and phenotypes; which is necessary for a genetics problem to exist. For example, in introductory biology courses, the inheritance patterns taught are simple dominance and codominance; problems with multiple alleles are a combination of the simple dominance and codominance inheritance patterns (Collins & Stewart, 1989).

On the other hand, a problem with a modifier has an inheritance pattern that also explains the relationship of phenotypes to genotypes but the distribution of genotypes and phenotypes in altered. The complication makes these problems more difficult to handle. In introductory genetics, the common modifier introduced is X-linkage. For example, in X-linkage, the cause of the modification is the location of the alleles on the X and Y chromosomes. The gene pair has a simple dominant inheritance pattern in individuals with an XX chromosome pair but is single allele (hemizygous) in individuals with an XY chromosome pair, causing a modification of the expected genotype to phenotype match. Most often, students might get confused by these problems even if they have a well-constructed meiosis model and content knowledge of genetics. One source of difficulty emerges when these students focus on only one part of the problem during the problem-solving process. They fail to look at the problem as an integrated whole. Therefore, even if they have a well-constructed knowledge base of the meiosis model and the content knowledge in the problem, they still fail to identify the problem class. Consequently, they fail to obtain a reasonable solution to the problem.

Although genetics knowledge structure is identified as the crucial element in determining problem-solving success, no research has been done to confirm this point. Further, the focus of attention has been on introductory biology courses. How about university advanced genetics courses?

In introductory genetics course, the problem type usually adopts the usual simple dominant inheritance model. In this model, two alleles determine each trait. For instance, alleles for any trait will be represented by "A" and "a" where they will combine to create three types of pairs of alleles (three genotypes: AA, Aa and aa). Within these three genotypes, there are two types of phenotypic variations: Variation 1, a dominant phenotype produced by two genotypes (AA and Aa) and Variation 2, a recessive phenotype produced by one genotype (aa). The simple dominant pattern works well with diploid organisms; those with two sets of chromosomal materials where two alleles determine the phenotype.

In advanced genetics course, the problem type usually deviates from the above simple dominant inheritance model. The organisms involved are usually haploids; in which one chromosome set determines the phenpotype. Griffiths et al. (1993) states that haploid organisms have a great advantage over diploids in mutation studies. The system of detecting haploid mutations is quite straightforward: any newly arisen recessive allele announces its presence unhampered by a dominant partner allele. In fact, the question of dominance or recessiveness never comes up in haploid organisms. In other words, a single allele can determine the trait of the haploid individual. However, genetics problems involving haploid organisms have never been addressed in the research literature of genetics learning. This type of realistic genetics problem fits into the "model-revising" problem suggested by Stewart and Hafner (1994). In solving this type of problem, students have to identify the problem class (e.g., crossing of haploid organisms) before they can revise their meiosis model to explain the different phenomena addressed in the problem. Results surely will advance the scope of research literature in genetics by (1) expanding the problem class for investigation and (2) extending the conception research in meiosis by including an investigation into the problem-solving process to predict success of students. *In order to study the entire problem-solving process of students, researchers have to adopt the phenomenographic perspective. The focus of this research perspective is on identifying in details ways in which learners understand phenomena or aspects of the world around them.*

The Phenomenographic Perspective

Phenomenographic studies identify categories of description which characterize how people conceptualize phenomena (conception research), and process information (approaches to problem-solving) as they are working on a

particular problem. These categories represent students' explanations as they are addressing the problem . The author believes that the part on information processing should be integrated into existing conception research in genetics. The findings of these integrative studies serve as a rich data set for arranging teaching and learning experiences.

During the last two decades, several studies of student learning in higher education have identified students' approaches to complicated problem solving tasks in different subject disciplines (Marton & Saljo, 1970; Svensson, 1977; Ramsden, Whelan & Cooper, 1989). Classical studies by Marton and Saljo, and Svensson related to reading of academic texts. Ramsden, Whelan and Cooper (1989) studied diagnostic problem-solving in medicine.

The classical studies above reported examples of students adopting what was termed deep and surface approaches-which have a "referential" and a "structural" component. In connection with the "referential" aspect, Marton and Saljo (1976) found that those students who adopted the deep-level processing viewed the learning situation as one that required them to extract personal meaning from the article. In other words, the intention of these learners was to understand the material being studied. Adopting a surface approach, students intended to reproduce the material being studied with no intention of making these materials their own. They focussed on separate words and sentences of the test, rather than on the meaning those words and sentences were intended to convey- "the signs of the text".

The "referential" aspect might well be applied to characterize students' intention in solving a genetics problem-understanding or reproducing content knowledge. For example, in a genetics problem involving the organism *Neurospora*, the genotype and phenotype of the parent are given as +f (+ being the wild type genotype for the colour beige, f being the mutant genotype for the colour fawn) and normal black colour respectively. Students might infer from the data that (1) the parent is haploid (since only one set of chromosome is given) and (2) the "+" and "f " are two separate gene loci on the same chromosome. However, those students who adopt the surface approach might treat this parent as if it were a usual diploid organism. They ignore the genotype(e.g., +f) given in the problem and change it to a "ff" genotype to explain the fawn phenotype. In this case, the recessive f gene for

thefawn colour, should appear twice (i.e., homozygous recessive) to show the fawn phenotype. In other words, students still adhere to the concept of the simple dominant inheritance model in diploid organisms. A reason to account for this phenomenon is that these students reproduce without showing actual understanding of the content knowledge of haploidy and diploidy.

Another part of the deep and surface approach is the "structural" component. Svensson described the structural aspect of student approaches in terms of the "holistic" and "atomistic" categories. In adopting a holistic approach, students seek to integrate and relate the material they are studying. On the other hand, adopting an atomistic approach, students attempt to memorize disconnected pieces of information without imposing any coherent structure on the material (Svensson. 1977). He also argued that students adopting an atomistic approach learned isolated bits of information whereas students adopting a holistic approach learned organizing principles that preserve the structure of the information. Applying Svensson's (1977) idea to genetics problem solving, an "atomistic" problem-solver focusses on all the information provided in the problem. For example, some genetics problems consist of both the descriptive and pictorial components. "Atomistic" problem-solvers concentrate on either the descriptive or the pictorial component without integrating them together and thus they fail to identify what is asked. On the other hand, "holistic" problem-solvers seek to identify what is asked in the question by considering the two components of the problem together. As a result, they recognize what is required in the problem.

Having considered both the "referential" and the "structural" aspects of the approach learning separately, two earlier studies suggested the importance of using the two aspects together to determine the success of students in conceptual change and in course study. In one study, Prosser and Millar (1989) used phenomenographic research techniques to focus on student learning in a first year university physics course. Results showed that there was a substantial relationship between approach to learning and conceptual change for all tasks (i.e., physics problems on force and motion) combined. Only those students who adopted a deep holistic approach showed conceptual change development over time. Another study was conducted by Eizenburg

(1988) on approach to learning adopted by medical students in an anatomy course. Results of the interviews showed that those students who employed a deep approach holistically gained a full understanding of the course. Other students who employed a deep approach atomistically searched for meaning in isolated items of information without relating the information to the whole problem. These learners are "horizontalising" the content (Marton & Saljo, 1984) and are unable to understand what the problem is asking. Similarly, in the context of genetics problem solving, this *phenomenographic perspective could be applied to investigate the entire problem-solving process. Both the referential and the structural aspects must be considered when we formulate the approaches.*

Conclusion

Past research in genetics focussed on probing students' conceptualizations of meiosis. These conception research did not examine the ability of students to apply this concept to a problem. The new ideas of Stewart and Hafner (1994) to include model-revising problem types in genetics open new scope for investigation in genetics learning. Future genetics problem-solving has to go beyond the conception research tradition and to investigate the problem-solving process of students. *In other words, other than examining the conceptualizations of a particular concept in genetics, students' ability to apply that concept to a problem should also be analyzed. These studies should be guided by the phenomenographic research perspective and take into account both the referential and the structural aspects of the approaches.*

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