# Teaching genetics in India: Problems and possible solutions

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**Abstract**

**Genetics is a difficult subject for majority of biology teachers and students world-wide. It is recognized that majority of students and even teachers of biology do not fully understand the basic concepts of genetics. They also experience difficulty in solving numerical problems of genetics. During the last few decades, this problem has become more acute due to the impact of molecular biology on genetics. In this article, this problem has been illustrated with the help of some examples of basic concepts, which the author thinks are difficult and are not fully understood by majority of teachers and students. The general problems in teaching of genetics described in this article include inherent variation in ability to understand among students, and resistance to follow scientific teaching among teachers, as demonstrated through well-designed logical experimentation. The solutions suggested for improvement of teaching include interactive teaching and preparations of inventory of difficult concepts, and clickers questions. The resources for improvement of teaching genetics that are being developed by Genetics Society of America (GSA) have been described in some detail. These resources also include some 'online web resources for teaching genetics', which include 'MendelWeb' and 'GeneEd' that are periodically revised. A set of questions in the form Genetics Concept Assessment (GCA) and a repository of clicker questions have been recommended as a regular activity of teachers for their own assessment followed by the assessment of the students in the class room. Arrangement of regular short training courses has also been recommended for the unpgradation of the prescribed contents of genetics courses, for developing newer teaching methods and also for the preparation of teaching material to improve the knowledge-base of teachers.**

**Key words:** Genetics, teaching, concept of genetics, school, college, university

## Introduction

Genetics has been a difficult subject for teachers to teach and for students to learn. This difficulty is encountered both at the school level and at the university level. Among biology teachers and students, misconceptions and lack of proper understanding of several basic concepts of genetics originate at early stages of learning genetics. In a National DNA Day Essay Contest conducted in USA, in a sample of ~500 essays submitted by students of grade 12, the misconceptions in ten different areas of genetics were 55.6% even after their answers were generally reviewed by their teachers (Shaw et al. 2008). In another study involving 70 prospective teachers also, the misconceptions and inability to solve problems were found to be a common feature (Karagoz and Cakir 2011). This limitation persists for long durations, if not corrected either by self-learning or through contacts with a good teacher. Also, during the last hundred years, the subject of genetics has witnessed an exponential growth approaching a fairly advanced level. Therefore, it has become almost impossible for a teacher to learn and understand all branches of genetics, starting from classical Mendelian genetics to cytogenetics, molecular genetics and quantitative/ statistical genetics. This makes the task of learning genetics difficult for teachers as well as students. Unfortunately teachers with good understanding of the subject of genetics and/or having commitment to teaching are rare, with the result that genetics (even classical genetics) is often taught by teachers, who are neither competent to teach, nor committed to teaching this relatively difficult subject.

Keeping in view the importance of the science of genetics and its role in plant breeding, the Indian Society of Genetics and Plant Breeding organized its 'First National Genetics Congress (NGC)' with the title "Genetics for Sustainable Food, Health and Nutrition Security". (December 14-16, 2018). This article is based on the lead lecture delivered by the author in the last

session of this 1st NGC. During the lecture, the discussion was restricted to only university level teaching of genetics, particularly in traditional universities, agriculture colleges and most state agricultural universities. In this article, the discussion is focussed on teaching of the basic concepts of genetics for general public and for students in schools along with teaching of genetics to biology/agriculture students at the university level. The article has been structured with two parts. The first part deals with an account of the present status of teaching genetics and the difficulties encountered in teaching and learning genetics. The second part is devoted to the possible solutions that are either already being used in different parts of the world or should be used in future. The article has been written with particular emphasis on teaching of genetics in India. Teaching of human/ livestock genetics will not be covered in this article.

**Phenomenal growth of genetics makes teaching difficult**

The history of genetics suggests that during the 20th century there was a phenomenal growth of genetics with one or more Nobel Prize winning discoveries made almost in every decade. These major developments facilitated and motivated the development of independent courses of genetics to be taught at the university level. Some universities also planned courses for the award of independent degrees in the field of genetics at the Bachelor and Master levels. Therefore, the universities needed individual teachers having expertise in specific areas of genetics, which included classical genetics, cytogenetics, biometrical and quantitative genetics, microbial genetics, bioche-mical genetics, molecular genetics, recombinant DNA technology, transgenic technology, genomics, etc. Epigenetics is another very important area, which is attracting the attention of many so that teachers and students also have to learn this new and emerging subject with its minute details. Each aspect of epigenetics had a major growth, so that DNA methylation, chromatin modifications and associated histone modifications (particularly methylation and acetylation of lysine residues in H3 protein) and a variety of no-coding RNAs (ncRNAs) all are becoming independent and important areas of research.

In order to learn the basic concepts of genetics at different levels of organization, it is also necessary for the students of genetics to have knowledge about the structure and function of the cell with its organelles, and also about cell division and reproduction. For instance, one has to learn the genetics of cell division, not only in eukaryotes, but also in prokaryotes, where the genetics of cell division was studied rather late. Model organisms were also chosen for the study of specific aspects of genetics, so that it is also necessary for the students of genetics to learn the life histories of the following model organisms: *E. coli*, *Neurospora*, budding/fission yeasts (*Saccharmyces cereviseae* and *Schizosaccharmyces pombe*), *Drosophila melaogaster*, *Arabidopsis thaliana*, *Coenorhabditis elegans*, etc.

**Present status of teaching genetics**

***Teaching of genetics at school and university levels***

Teaching of genetics is not only important for students of biology at the university level, but also for students at the school level to provide literacy in genetics among the general public to be able to appreciate the role of genetics in solving problems of food security and human healthcare. In recent years, these problems are being addressed through the supplementary use of recombinant DNA technology and genetically modified (GM) or gene-edited crops on the one hand and through the study of the genetics of thousands of human diseases and their diagnosis, prevention and treatment on the other. A detailed study of the genetics of diseases also helps in the development of drugs and treatments like gene therapy, genome/gene editing.

The knowledge of genetics among the general public is also important because certain products of recombinant DNA technology are often subjected to public opinion, and the public responds through proxy due to the publicity by the activists, who make anti-science propaganda for achieving their own goals, even if these are against the general public good. Based on public opinion, a moratorium on Bt-brinjal, the product of genetic engineering was imposed by the Indian government, which provides a good example of the harm done due to lack of genetics literacy among public (Gupta et al. 2015).

Studies have been undertaken in Europe and USA to examine the problems and possible solutions associated with teaching of genetics at all levels, starting from schools to PhD levels. Unfortunately, no regular studies on genetics education of the kind conducted in Europe and USA have been undertaken in India to assess the level of knowledge and understanding of the subject of genetics among students. The only study on teaching of genetics conducted in India is based on an analysis of students

in the schools of North-East region of the country, which may be considered to be a representative sample from India (Chattopadhyaya 2005; see later for some details).

### Understanding the concepts of genetics: Some examples

In order to discuss the status of understanding the basic concepts in genetics, some examples in specific areas of genetics have been selected to illustrate the problem of understanding concepts of genetics and data analysis: (i) Mendelian-Morganian Genetics (segregation and independent assortment; meiosis and reduction division including double reduction; three-point test-cross and genetic mapping using a mapping function); concept of gene/allele based on resolution of genetic system (Pontecorvo 1958), (ii) Cytogenetics (Barbara McClintock's work); chromosome mapping using structural and numerical changes, and genome analysis using wheat as an example; and (iii) Quantitative Genetics (QTL analysis using interval mapping and GWAS); likelihood and probability including posterior probability and Bayesian methods for analysis.

#### Segregation and independent assortment

While teaching genetics, often the teachers do not explain the physical basis of Mendel's Laws of Inheritance and the chromosome theory of inheritance. They fail to draw a parallel between segregation and independent assortment of genes and the behavior of chromosomes during different stages of meiosis leading to gamete formation. Often the students do not understand that segregation of traits takes place due to separation of two homologous chromosomes (carrying different alleles, say A and a) either at the first division of meiosis or at the second division (in the event of crossing over between the gene and the centromere). It is also not appreciated that the chromosomes in different pairs of homologous chromosomes pass on to two poles rather independently, thus giving all possible combinations in equal proportions. This is the basis of what Mendel described as independent assortment of factors controlling more than one traits.

#### Meiosis: Reduction division versus equational division

Cell division is taught to students of biology at all levels, but seldom if ever, the teachers and the students understand the actual meaning of reduction division, and always erroneously attribute this to reduction of chromosome number. The teachers and students therefore fail to appreciate that reduction division can take place even without reduction of chromosome number, as exemplified by double reduction in polyploids. In terms of genetics, the reduction division means reduction in the number of alleles in a cell carrying two alleles at the same locus. In other words separation of two alleles present on two homologous chromosomes to the two poles is the reduction division, whereas separation of alleles present on two chromatids of the same chromosome to the two poles is the equational division. Therefore, students need to learn that reduction division is actually disjunctional division, which means separation of non-sister chromatids to two different poles in the cell as against equational division, which means separation of sister chromatids to two poles (remember that separation of segments of sister chromatids due to crossing over, but both still going to the same pole, is still a reduction division, as is possible in polyploids).

#### Meiosis and double reduction in polyploids

Teachers and students of genetics often find it difficult to appreciate the meaning of chromosome segregation vs chromatid segregation, while discussing genetics of polyploids. Therefore they also fail to appreciate the meaning of 'double reduction' in meiosis, which results in the formation of gametes with the genotype 'aa' from a tetraploid plant with the genotype AAAa (triplex), which should produce gametes only with two genotypes, namely AA and Aa, if we assume chromosomal segregation. They fail to appreciate that the same allele 'a' on two sister chromatids can go to the same pole even after separation due to crossing over, and then to the same pole in the meiosis II, thus causing double reduction as shown in Fig. 1.

#### Linkage maps and mapping function

While teaching the method for construction of linkage/genetic maps, we always teach the students that the genetic distance is directly proportional to the recombination frequency between any two genes. Often we do not teach them the two exceptions to this general principle: first that the concept of linear relationship between genetic distance and recombination frequency holds good only till the recombination frequency is not more than 10%-20% (this relationship fails at higher frequency of recombination; see Fig. 2); second that the recombination frequencies per unit physical distance (even at smaller physical distances) differs not only
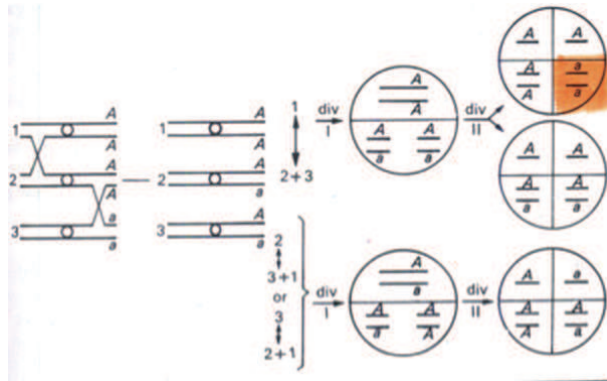
**Fig. 1. The process of gamete formation in a trisomic/ triploid organism, showing the phenomenon of double reduction leading to the formation of 'aa' gamete (derived from segments of sister chromatids, each carrying 'a' in an organism with simplex genotype (AAa)**
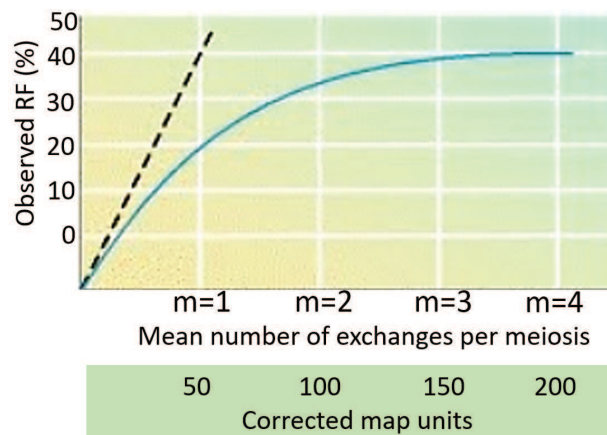


**Fig. 2. Relationship of recombination frequency (RF %) with map units (in cM; corrected using mapping function), mean (m) number of exchanges per meiosis between the two loci under consideration**
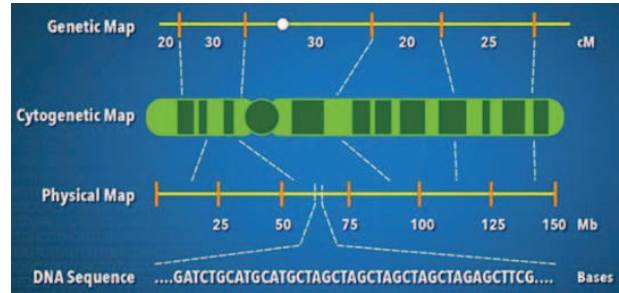


**Fig. 3. Lack of relationship between genetic and physical distances due to variation in recombination frequencies in different regions of a chromosome**

**Table 1.** Haldane and Kosambi mapping functions that are used for calculating genetic distance (x = map units in cM) using recombination frequencies (r)

|  | | Haldane | Kosambi |
|---|---|---|---|
| X | = | $-\frac{1}{2}\ln(1-2r)$ | $\frac{1}{4}\ln(1+2r)/(1-2r)$ |
| r | = | $-\frac{1}{2}(1-e^{-2x})$ | $\frac{1}{2}(e^{2x}-e^{-2x})/(2^{2x}+e^{-2x}))$ |
| $r_{AC}$ | = | $r_{AB}+r_{BC}-2r_{AB}r_{BC}$ | $(r_{AB}+r_{BC})/(1+r_{AB}r_{BC})$ |



**Fig. 4. Use of clickers as personal response system in a classroom, permitting rapid and anonymous collection of answers to a question from every student in the class**

*Difference between cytogenetics and genetics*

Often the teachers and students of genetics also fail to make a clear distinction between cytology (study of chromosomes and other components of the cell), genetics (study of genes) and cytogenetics (study of genes and their location/assignment to chromosomes). Many laboratories in India undertaking chromosome

in different parts of the same chromosome, but also in same relative positions of different chromosomes (Fig. 3). Therefore, a mapping function is required to prepare a genetic map involving long distances (Table 1). The teachers, in general, do not even mention about the mapping function, while dealing with construction of genetic maps using recombination frequencies. Among those few, who make a mention about the mapping function, hardly any would elaborate the difference between mapping functions proposed by JBS Haldane and DD Kosambi (Haldane mapping function ignores interference, while that of Kosambi takes interference into consideration: Table 1).

research describe their research as cytogenetics without realizing that unless you are studying genes and their relationship with chromosome, it is not cytogenetics. One of the popular example of cytogenetic studies is the construction of linkage maps and their assignment to individual chromosome and a comparison of genetic maps and physical maps of chromosomes in any species. Other examples of cytogenetics research include assigning genes to chromsomes using different kinds of structural (duplications, deletions, inversions and translocations) and numerical changes in chromsosomes (trisomic analysis in maize and barley; monosomic analysis in wheat). The classical examples of the use of duplications/deficiencies in fruitfly (*Bar* locus in *Drosophila*), maize (pale yellow leaf colour of seedlings) and a variety of traits in tomato (Khush and Rick, 1968) illustrate how cytogenetics really differs from genetics on the one hand and chromosome research on the other. For instance, if one is conducting research on induction of mutations and also studies chromosomal abnormalities due to treatment with irradiation and chemicals using the same plant material, this can not be treated as cytogenetics, although both genetics and cytology is included in such a research program.

The basic concepts involved in cytogenetics research can be illustrated using the following examples of classical experiments, which need to be taught to all students of genetics: (i) experiment of Curt Stern (1931) in fruitfly (*Drosophila melanogaster*) and that of Creighton and McClintock (1931) in maize (*Zea mays*) for cytological basis of crossing over; (ii) experiments of Brink and Cooper (1931) demonstrating linkage of sterility (caused due to interchange heterozygosity) with two different linkage groups in maize. (iii) Development of physical maps in tomato using deletions and pseudodominance in tomato using pachytene chromosomes. (iv) Comparing genetic maps developed in common wheat using mapping populations with physical maps developed using 42 different compensating nullisomic-tetrasomic (NT) lines developed by ER Sears (1954) and >400 deletion stocks developed by Endo and Gill (1992).

### Fine structure of gene: cistron, recon and muton

During 1940s, for the first time, our concept of gene and allelomorphism changed for ever through the work of Green and Oliver on lozenge locus and that of EB Lewis on the locus for eye colour in Drosophila. They reported complementation between two mutant alleles of the same gene. Lewis (1951) described such alleles as pseudoalleles, and the phenomenon as pesudoallelism, since the mutant alleles did not fit the widely accepted definition of alleles at that time. Later due to the discovery of intragenic recombination, and the study of cis-trans effect at *rII* locus of T4 phage by S. Benzer, the concept of cistron was proposed and the terms cistron, recon and muton were suggested as units of function, recombination and mutation respectively. Majority of teachers and students can not appreciate that the term cistron for functional unit was coined to suggest that the elements of a cistron should exhibit cis-trans effect.

### Basic concepts for QTL analysis

QTL analysis is now conducted in several laboratories in India, but the students conducting these experiments seldom understand and appreciate the basic concepts involved in QTL analysis. For instance, they would seldom understand that in a segregating population, each marker genotype (e.g. Aa and aa in a backcross and AA, Aa and aa in a conventional $F_2$) consists of more than one QTL genotypes (QQ, Qq in backcross and QQ, Qq and qq in $F_2$), so that a mixture model needs to be applied. Also a likelihood function is used, where we determine the likelihood ratio (LR) using the likelihoods of getting the observed results, if QTL is present and if QTL is absent. The students of genetics, even those, who are conducting QTL analysis for their PhD work seldom (if ever) understand and appreciate the following likelihood function that is utilized in maximum likelihood approach of QTL analysis using backcross progeny.

$$L = \frac{1}{(\sqrt{2\pi}\sigma)^N} \prod_{i=1}^{N} \prod_{j=1}^{2} p(Q_j / M) \exp\frac{[(y_i - \mu_i)^2]}{2\sigma^2}$$

## Difficulties and issues in teaching genetics

Difficulties in teaching genetics can broadly be classified into two groups: difficulties of general nature involving teaching in general, and problems of specific nature associated with teaching of genetics in particular. We will discuss them separately.

### General problems in teaching

General difficulties in teaching are those, which are relevant to all subjects and will be briefly described, because these are equally relevant to the subject of genetics also.

*Ability to learn: The genetics of education*

It has been shown that the teaching of genetics also depends partly on the ability to learn, which seems to be genetically controlled. Lee et al. (2018) conducted GWAS using a sample of approximately 1.1 million human subjects and identified 1,271 SNPs that were associated with ability to learn. For all the SNPs taken together, there was an evidence of heterogeneous effects across environments. The study gave evidence that there are genes involved in brain-development processes and neuron-to-neuron communication, thus influencing ability to learn; however, no gender variation in learning ability was observed. In the class-room also, we observe that all students taught by the same teacher have different levels of learning. This calls for a greater effort on the part of a teacher to teach students, who possess a lower level of ability to learn.

*Resistance to scientific teaching*

Scientific teaching involves effectiveness of active learning techniques, and emphasizes on strategies to engage students in teaching following teaching methods that have been systematically tested and shown to reach diverse students. However, despite proofs about the success of these learning strategies, it is surprising that these learning strategies have not been widely adopted by teachers in the universities. It has also been observed that, majority of teachers resist changing their teaching, and want to continue with the teaching methods that are not the most effective? Others feel intimidated by the challenge of learning new teaching methods; there are also teachers who fear that their identity as good teachers will reduce their credibility as good researchers (Handelsman et al. 2004). Consequently, teaching is often neglected by a section of teachers on the pretext that they are too much occupied by their commitments to research. For the same reason, good teachers having good knowledge of the subject often hesitate writing good text-books for the students.

Scientific teaching and learning needs to be approached with the same rigor as science itself. According to a 2004 Policy Forum in *Science* magazine [a weekly journal published by American Assoc for Advancement of Science (AAAS) in USA], "scientific teaching involves active learning strategies to engage students in the process of science and teaching methods that have been systematically tested and shown to reach diverse students" (Handelsman et al. 2004). Later in 2007, in a volume on *Scientific Teaching*, the following three major tenets of scientific

teaching are listed: (i) *Active learning*, in which students are actively engaged in learning. It may include inquiry-based learning, cooperative learning, or student-centered learning. (ii) *Assessment*, where a variety of tools are used for measuring progress toward and achievement of the learning goals. (iii) *Diversity*, which makes each student unique, each cohort of students unique, and each teaching experience unique. Diversity includes everything in the classroom: the students, the instructors, the content, the teaching methods, and the context.

The above three elements should underlie educational and pedagogical decisions in the classroom, but are seldom followed by the teachers. The "SCALE-UP" learning environment is an example of applying the scientific teaching approach. In practice, scientific teaching should employ a "backward design" approach, which involves the following steps: (i) The teacher should first decide what the students should know and should be able to achieve (learning goals); (ii) the teacher should also determine what would be the evidence of student achievement of the learning goals; (iii) the teacher then designs assessments to measure this achievement, and finally, (iv) the teacher plans the learning activities, which should facilitate student learning through scientific discovery.

### Specific problems in teaching genetics

Teaching of genetics is now undertaken at all levels including junior/secondary school levels and undergraduate/post-graduate levels (both MSc and PhD), and will be discussed separately.

*Teaching in schools*

At the international level, a series of studies were conducted jointly by the following two centres to assess the level of understanding of genetics among those who passed out after compulsory elementary and secondary school education; (i) The Centre of Studies in Science and Mathematics Education at the University of Leeds in UK and (ii) Mathetmatics, Science, Technology and Education Center, Pietersburg (now known as Polokwane), South Africa. In all such studies a sample of students were given a set of multiple choice or true/false questions and their answers collected to assess the status about the understanding of the basic concepts in genetics. It was shown in most of these studies that understanding of genetics and its various aspects is poor among students of various levels and among the population

in general (Lewis and Wood-Robinson, 2000; Lewis et al. 2000a, b, c; Lock and Miles, 1993; Lock et al. 1995; Marbach-Ad, 2001; Marbach-Ad and Stavy, 2000; Michie et al. 1995; Ponder et al. 1996; Scriver, 1993; Wood-Robinson, 1994, 1995; Wood-Robinson et al. 2000).

A cross-national study of teaching genetics to students at the school level in UK and Turkey was also conducted by Kilic et al. (2016). The results indicated that there are some differences between the English students' and Turkish students' in the understanding of fundamental concepts of genetics; however, there are some notable similarities between the alternative concepts held by students in the two samples. The common alternative concepts seen in both the groups indicated that difficulties in understanding the concepts occurred regardess of contextual factors. Nevertheless, different proportions of the common alternative concepts and different levels of understanding suggest that conceptualisations develop under the influence of different educational contexts.

In India, in a solitary study, Chattopadhyay (2005) made an effort to examine knowledge and understanding of concepts related to cell biology and reproduction that are important for an understanding of the concepts of genetics (Table 2). For this purpose, the same questionnaire was used that was used in earlier studies in UK (Lewis et al. 2000a, b, c) as part of the "Learning in Science Research Group". In UK, this questionnaire was used for middle school children, but the same questionnaire was used in this study for higher secondary students. The questionnaire had two parts: the "Cells" section and the "Reproduction"

section. It combined both fixed- and free answer–type questions. None of the students could give correct answers to all the questions, and a large section of students were found to lack proper understanding of the basic concepts about genetic information that is available within different types of cells, and hardly 1% students knew that the chromosome constitution of sperms and eggs differ.

*Teaching in colleges and universities*

In USA, a series of studies were conducted to assess the status of teaching genetics at the undergraduate level in universities. In all such studies, it was found that a fairly high proportion of students lacked proper understanding of the basic concepts of genetics. In India, the situation is worse, where often the students fail to explain even the physical basis of Mendel's laws using meiosis.

Apparently, no studies have been conducted any where in the world on the status of teaching genetics at post-graduate (M.Sc) and doctoral (PhD) level. The worst aspect of teaching of genetics is at the PhD level in India, where there are hardly any examples of failures; every student registered for PhD degree is guaranteed a PhD degree, irrespective of whether or not he/she deserves it, and whether or not he/she learnt the basic concepts of genetics.

**Table 2.** Portions of cell biology and genetics syllabus taught at the higher secondary level in Meghalaya Board of School Education, Meghalaya

| Subject & Topic | Item |
| --- | --- |
| Genetics (classical)<br>- Continuity of life<br>- Mendel's Laws<br>- Chromosomes | Heredity, variation, incomplete dominance, multiple alleles, multiple factors<br>Chromosome theory, linkage & crossing over/linkage maps, sex chromsomes, sex linkage, sex determination, chromsosomal aberrations, human genetics, bacterial genetics, etc. |
| Genetics (molecular)<br>- DNA as genetic material<br>- Recombinant DNA | DNA: structure/replication; protein synthesis, transcription, translation; regulation of gene expression, etc<br>Vectors, cloning; DNA fingerprinting, transgenics, genomics |
| Cell biology<br>- Cell as basic unit of life<br>- Cell cycle and cell division | Discovery of cell, cell as unit of life, cell division-mitosis and meiosis |

In USA, the Genetics Society of America (GSA) has been interested in the improvement of teaching of genetics and therefore several articles have been published in their journal 'Genetics' (Smith et al. 2008; Bowling et al. 2008; Smith and Knight, 2012; Smith and Wood, 2016). A group at the University of Colorado, Boulder under the leadership of Michael Smith has

regularly undertaken studies to examine the problems and provide solutions for improvement in teaching genetics. According to these reports, even among students in USA, there seems to be large-scale poor understanding of the basic concepts of genetics and genetic technologies, with widespread misconceptions at various levels.

The shortcomings of teaching genetics at the graduate and post-graduate levels, are many-fold and are mainly associated with quality of teachers and their commitment, and therefore also with the methods, which the teachers follow in teaching genetics. Knowledge/memory based teaching is not as big a problem, as is the understanding of the basic concepts in genetics, problem solving, reasoning, application and data analysis, sometimes also at the molecular level. Most of the teachers of genetics unfortunately did not have good teachers themselves and therefore never developed a taste for the subject of genetics. These teachers generally provide information and knowledge-base to memorise, but never make the students understand concepts, analyse data and solve problems.

A study of teaching genetics at the undergraduate level was also conducted in Brazil (Infante-Malachias et al. 2010). In this study, questionnaires were supplied in six different Brazilian undergraduate courses (Biology, Medicine, Dentistry, Psychology, Nutrition and Phonology) to analyze students' comprehension of basic concepts of genetics. All sampled students together were not able to answer 30% of the questions, while a significant percentage did not adequately answer more than 60% of the questions. The differences in performance between first-year and last-year students of an undergraduate Biology course were evaluated. Interestingly, first year university students, without any formal education in genetics at the university level, performed frequently better when compared with their last-year colleagues. Results of the above study revealed that future teachers and other health professionals share distorted understanding of elementary genetics. This finding is of particular interest, reflecting a relationship between acquisition of the genetic knowledge and professional development.

*Teaching involving laboratory exercises* (Practicals)

The situation of teaching in practical classes in the laboratory is worse than teaching theory in the class-rooms. In many cases, the teachers themselves are incapable of conducting the experiments, which the students are supposed to conduct, with the result that the students pass out with know skill about conducting experiments in the laboratory. For instance, almost >90% of universities and colleges teaching genetics do not have teachers, who can prepare a slide to study mitotic or meiotic chromosomes, and perhaps, none who could prepare slides for karyotype construction or for the study of meiotic chromosomes (univalent, bivalents and multivalents); of course there may be exceptions to this generalization. These observations are based on author's own assessment of the situation in India.

**What can be done to improve teaching of genetics?**

Since it is widely recognized that genetics is a relatively difficult subject and that there are problems with teaching genetics, solutions have been sought, which are also available in the published literature and on the web. Indian Society of Genetics and Plant Breeding also took an initiative in 1998, and organized a "National Symposium on "*Meeting the Future Needs of Higher Education in Genetics & Related Disciplines-Courses and Curriculum*" and published its Proceedings as a Special Issue of the Indian J Genetics & Pl Breeding (Kharakwal and Mehra 2001).

Major efforts in the field of 'Genetics Education' and 'Teaching of Genetics' were made by the Genetics Society of America (GSA). An Education Committee (as one of several committees) was constituted by GSA to address the problems of genetics education that also includes teaching of genetics. This Education Committee established a Peer-Reviewed Education Portal (PREP) in 2012 to promote high-quality classroom resources for undergraduate courses. These resources are vetted and used evidence-based teaching methods (those shown to be effective in enhancing student learning and retention). Each resource fits into the learning framework, which consists of (i) Core Concepts and (ii) Core competencies; these are revised periodically as needed by the GSA Education Committee, which is supposed to promote the principles of teaching genetics. American Society of Plant Biologists (ASPB) through their journal The Plant Cell also initiated a program called 'Teaching Tools'; under this programme, articles are published regularly for the benefit of teachers. Some of these Teaching Tools fall in the area of genetics and therefore, can be utilized by the teachers of genetics. A brief account of these teaching tools will also be presented later in this section.

GSA also created a Genetics Education Resource Room, which is a facility with a collection of animations, games, simulations, videos, problem sets, PPTs, and readings for the classroom, all organized subject-wise. One can click on a category (several categories are provided on the site). Each sub-category will take you to a list of resources, where one can make a choice and utilize the facility for classroom teaching. This Resource Room keeps on evolving based on the suggestions received by GSA. The monthly journal 'Genetics', which is the official organ of GSA, also regularly published invited articles on teaching of genetics (Wood, 2004; Smith and Knight 2012; Smith and Wood, 2016). In these articles, the authors point out some major problems and also provided some solutions. Three major shortcomings and possible solutions discussed in these research papers include the following: (i) the lack of interactive teaching for 'active learning'; (ii) lack of regular assessment using a set of questions described as "genetic concept assessment" (GCA), and (iii) lack of awareness and recognition of the fact that there is diversity among students, who differ in the level of background and level of ability to learn. Some of the solutions will be discussed in this section. These solutions are based firstly on published literature (in print or online), and secondly on author's own 60 years of teaching genetics to university students, first at Gorakhpur University (1960-69), and then at Meerut University (now called CCS University Meerut) for almost 50 years.

### Interactive/scientific teaching

It has been recommended at several fora and in different parts of the world that traditional teaching through formal classroom lectures involving transmission of information in the form of a cook-book is not effective. This is particularly true for the relatively difficult subject of genetics. Therefore, introduction of interactive teaching has been recommended. This newer method has not been used on any large-scale, but wherever practiced, has been shown to result in higher gains in learning. As mentioned earlier, the interactive teaching is described as 'scientific teaching' with the three components (mentioned earlier in this paper), which will be discussed here with reference to teaching of genetics, although these would apply to the teaching of all subjects.

### Active learning

The traditional method of teaching involves delivery of lectures. In active learning, the students are actively engaged in learning process that includes enquiry-based learning, cooperative learning, or student-centered learning. Although, this enquiry-based learning is time-consuming and reduces the coverage of course content in a one-hour or two hours class, it increases the chances of knowledge acquisition by the students. Considerable literature is available on 'active learning', which has been followed by a rather insignicant proportion of teachers world-wide. Active learning has also been described as 'classes without lectures', where students are sometimes made to collect and analyse actual data. This leads to higher content retention and student satisfaction. Some of the methods adopted in active learning include the following (on-line literature is available for each of these): (i) problem-solving by students individually or in groups; (ii) case studies; (iii) inquiry based lab exercises; (iv) interactive computer learning, Voluminous literature on active learning is actually available and was described and discussed in an article published as early as 2004; useful supplementary on-line material was also made available in this article, which may be consulted by the inquisitive readers (Hnadelsman et al. (2004);. Active learning sometimes also involves students in original research in the laboratory of the teacher, although many teachers do not like the idea, because this may cause a disturbance in the regular research projects that are in progress in the lab.

Methods have also been suggested to bring about a change from classroom lecturing to active learning. Universities should provide leadership in bringing about this reform through overcoming the common barriers. On their web page (www.genetics. gsa.org/education), GSA suggested the following four steps, which a teacher of genetics may follow while teaching genetics: (i) Determine your learning objectives (using Genetics Learning Framework of GSA as a guide); (ii) Choose resources that cover your learning objectives, and use interactive features in the classroom involving active learning. Useful resources are available at CourseSource (an online journal), GSA PREP and LifeSciTRC. GSA has also recommended the use of Primers linked with primary literature; these Pimers are available on GSA website. (iii) Learn more about discipline-based education research; and (iv) don't stop there; continue learning and using available resources (resources are available in the form of concepts and competencies).

## Concept inventory

It has also been recommended that a teacher should have an inventory of concepts that are essential to be learnt and mastered by the students, but are difficult to understand by a sizable section of students. This inventory should consist of series of questions designed to determine whether a student has an accurate working knowledge of a specific set of concepts for a given field. In other words, a concept inventory is a set of multiple choice questions (MCQ) designed to probe student's understanding of these fundamental concepts.

## Clicker questions for teaching genetics

One of the tools that has been devised for interactive teaching and active learning is the use of clickers (personal response systems). These clickers are hand-held devices and resemble TV remotes with several buttons labeled numerically or alphabetically. At the start of the semester, the students can buy these clickers on the campus bookstore at a cost ranging from $5 to $30 and register with the course software, which connects the serial number of the clicker with the name and e-mail address of the student. The same clicker device can be used in more than one courses thus becoming economical for the students. Each class room is also equipped with receivers, which may be wall mounted and connected through wires with the instructor's computer or may be potable wireless devices. Cost of receiver and the software in a classroom is approximately $1000 that can be used for a number of courses taught in the same classroom. This cost must have come done during the last 15 years (2004-2019).

When the teacher gives a multiple choice question, the student can respond with the help of the clicker (Figure 4), so that the answer to a questions is received and stored and displayed in the form of histogram with the help of a projector, so that the class knows in real-time the proportion of students responding with wrong answers. After the answers are known, the students may be allowed to have group discussions and may be subjected to the interactive session again, so that they may be able to send their answers again, showing improvement in the performance due to group discussion. These clickers also provide feedback to the teachers for giving scores to students for their performance and also for further action by the teacher with individual students.

In order to use the clickers for active and effective learning, the teachers will have to carefully design clicker questions, which should be a regular exercise. The clicker questions should actually be based on the learning goals and should be revised on the basis of the discussions held in the classroom and also on the basis of the responses received from the students. Clicker questions may now also be available in the databases.

## CourseSource, a teaching resourse

*CourseSource* is an open-access journal of peer-reviewed teaching resources for undergraduate biological sciences, and was created in 2013 by *Howard Hughes Medical Institute* (HHMI). In this journal, articles are organized around courses in biological disciplines and aligned with learning goals established by professional societies representing those disciplines. GSA is a partner with this journal for their course on genetics, so that appropriate resources from GSA PREP, are posted on the CourseSource website. Authors may choose to submit their resource to CourseSourse instead of GSA PREP; in that event, the resource will be cross-posted in GSA PREP. One can also follow CourseSourse on Twitter (@CourseSource) to receive notifications about newly published articles and announcements. Keeping this in view ISGPB may also explore the possibility of joining CourseSourse and participate in developing resources for teaching genetics.

## Peer-Reviewed Education Potal (PREP)

GSA also created another facility called 'Peer-Reviewed Education Portal (PREP)' that was founded in 2012 in an effort to promote high-quality classroom resources for undergraduate courses in genetics. These resources are vetted and make use of evidence-based teaching methods (those shown to be effective in enhancing student learning and retention). The learning framework (CourseSource) has a list of 12 core categories (each category having a number of core concepts) that the teacher needs to master and 12 core competencies (regularly revised as needed by the GSA Education Committee), which the students are supposed to achieve after finishing a major course in genetics.

GSA PREP generated the above resource called CourseSource (including the core categories/core concepts), which may help teachers to overcome the problems of teaching. These resources include the following: In-Class Exercises, Laboratory Exercises, Laboratory Protocols, and Images/Animations, as well as whole courses. These are peer-reviewed and use

evidence-based teaching methods to ensure that using these resources will make your course effective and engaging.

GSA PREP is also a partner with Life Science Teaching Resource Community (LifeSciTRC), which is an online community with 600 registered users and a library of more than 6,700 peer-reviewed teaching resources for life science educators at all levels. All original resources published in GSA PREP are deposited in this library, and join life science resources from eight other professional societies.

*Primers as a tool for teaching genetics*

GSA also emphasized that consultation of primary literature should be an integral part of teaching. Keeping this in view, in the year 2012, the journal Genetics initiated publication of articles, which they described as Primers (Hawley 2012). Through these Primers, the undergraduates and graduate students (MSc and PhD students) are made to critically analyze original articles. Use of Primers was proposed to become a vital component of training them to be scientists, to understand how science is actually done, and to read and think critically. With such tools, the students explore the process of science first hand and learn how our research community presents its findings.

The practice of using Primers in genetics is in contrast to the exposure of students to some classic articles, which is equally important, but Primers are different. GSA proposed that each Primer published in Genetics will be tied to a current article in GENETICS and will lay out the necessary background (i.e., what was the question and why did that question matter?), explain the hypothesis or approach, describe the methodology, guide the reader through the results, and provide a precise summary of the discussion. The goal has been not to replace the article, but rather to make the article itself accessible by offering a road map. Having a Primer in hand will make choosing an article and teaching it effectively much easier for teacher. Thus a Primer will be the "jumping off" point that allows the students to dive confidently into the article.

Two kinds of Primers are published in Genetics. (i) *Primer on a current article*. This is the predominant type of Primer, which is tied to a current article in *GENETICS* and lays out the necessary background (*i.e.*, what was the question and why did that question matter) (ii) *Organismal primer*. This is the second type

of Primer, which covers a specific model organism, and is independent of a research article. These Primers serve more generally as an introduction to the genetics of a model organism. Each organismal primer will cover a model system used for genetic studies, and includes the life cycle, history of use in the laboratory, available genetic and genomic tools, advantages of the system, discoveries made using the model organism, etc. A Model Organism Primers can be assigned to a student along with a Research Primer featuring that model organism. They would also be quite useful for researchers in a new laboratory who would like to start using a new known model organism.

In essence, the Primer is a road map that aids instructors wishing to use peer-reviewed articles as the vehicle with which to develop many of the core competencies in genetics. For more information, see "The Other Life of Articles" (Hawley and Ruedi, 2012). A list of Primers is available on GSA's web site.

### Online web resources for teaching genetics

A number of online resources are also available for genetics education. Most of these learning modules have been developed by National Human Genome Research Institute (NHGRI) and are available on the internet (the readers may Google search for these resources and use them). Although most of these resources deal with human genetics and human genome, there are also resources which deal with fundamental concepts of genetics. Two modules that are useful for teaching genetics include the following: (i) MendelWeb: this is a resource developed in 1997 to help teachers and students with the concepts in classical genetics; the resource is being revised and the new version should soon become available; (ii) GeneEd (The GeneEd website was developed and maintained by National Library of Medicine (NLM), National Human Genome Research Institute (NHGRI) and National Institute of Health (NIH) in USA. The GeneEd is a useful resource for students and teachers of genetics, particularly for grades 9-12; there are separate pages for "Teachers Resources" and "Careers in Genetics"; however, this resource retired on March 31, 2019 and the contents transferred to Genetics Home Page, which is another online resource developed by NLM.

### Teaching tools (The Plant Cell)

Problem of teaching of plant science (including genetics) was also addressed by the journal The Plant Cell by initiating a special section under the title

'Teaching Tools' that was started in 2009. Under this program, ~40 feature articles on special topics were published, which included teaching guide/tools, power point presentations, questions to examine the understanding and the questions for discussion, etc. Under this series, they have also published articles on subjects like Genetics of Flower Development, Small RNAs and Epigenetics, which may prove useful for teaching genetics.

**Regular assessment**

Regular assessment of the learning by the students is essential to improve teaching. This will include the following activities: (i) Arranging regular and frequent assessment of students through sets of GCA questions, and to identify the problems and then find solutions; this has to be a major activity, which ISG&PB can undertake with all seriousness. (ii) Development of a repository of clickers and GCA questions (adequately reviewed and validated) and make it available to the teachers for their own assessment followed by the assessment of the students in the class room. (iii) Arranging regular short courses for developing newer teaching methods and to prepare teaching material to upgrade the knowledge-base of teachers. For this purpose, one or more teachers training courses should be arranged every year; alternatively, annual summer institutes be arranged for teaching genetics. If necessary, ICAR should be approached for necessary funding for this purpose. In this connection, ISGPB may utilize the resources available with GSA, and popularize them among Indian teachers involved in teaching genetics. This should be done at all levels including PhD level, so that the training proves useful not only for teaching, but also for conducting research in the emerging areas. Since GSA has a major activity in this direction and has developed useful resources, a brief account of activities of GSA in the area of Genetics Education will be described.

***Genetics Concept Assessment* (GCA)**

Smith et al. (2008) developed and validated the Genetics Concept Assessment (GCA), consisting of 25 multiple-choice questions, designed to be clear, concise, and as free of jargon as possible. The questions assessed understanding of a set of basic concepts likely to be taught in both major and minor genetics courses. The GCA is designed to be administered at the start of a course as a pre-test and at the end of the course as a post-test, to measure student learning gains (Hake, 1998).

The GCA questions were validated through student interviews, pilot testing, and expert review. Statistical analysis of test answers for 600 students at three institutions demonstrated that the GCA has an acceptable range of question difficulty and shows high reliability when taken by two similar populations of students in subsequent semesters. The method for the use of GCA can be used to evaluate which concepts students have learned well and which still cause them persistent difficulties after taking a genetics course.

In a follow-up study, Smith and Knight (2012) analysed the responses of students to multiple-choice questions from the Genetics Concept Assessment (GCA) to help genetics instructors become aware of fundamental concepts that are persistently difficult for students. In total, they examined pre-test (before instruction) and pos-test (after instruction) responses from 751 students enrolled in six genetics courses, either as major courses or as minor courses. It was observed that the students improved on all 25 questions after instruction, but to varying degrees. Notably, there was a subgroup of nine questions for which a single incorrect answer, called the most common incorrect answer, was chosen by 0.20% of students on the post-test. To explore response patterns to these nine questions, they tracked individual student answers before and after instruction and found that particular conceptual difficulties about genetics are both more likely to persist and more likely to distract students than other incorrect ideas. They presented an analysis of the evolution of these incorrect ideas to encourage instructor awareness of these genetics concepts and provide advice on how to address common conceptual difficulties in the classroom.

According to Smith and Wood (2016), genetics teaching at the undergraduate level has changed in many ways over the past century. Compared to those of 100 years ago, contemporary genetics courses are broader in content and are taught increasingly differently, using instructional techniques based on educational research and constructed around the principles of active learning and backward design. Future courses can benefit from wider adoption of these approaches, more emphasis on the practice of genetics as a science, and new methods of assessing student learning.

***Inequity and diversity among students and how to deal with it***

Inequity and diversity among students in a classroom is another challenge that need to be addressed by a

teacher. It is widely known that there are profound differences among different demographic groups in their educational achievements and patterns of science learning. These students with different levels of achievements and ability to learn should get the same opportunity to learn in the classroom. It needs to be recognized that individual students and cohorts of students in a classroom are unique, and following different strategies for teaching these diverse classes of students can really be a challenge. Therefore, a teacher need to prepare plans to pay extra attention to these diverse students. An inclusive teaching is recommended for this purpose. Following core practices are also recommended for this purpose: (i) Design courses with inclusivity in mind. (ii) Learn about the students at the beginning of the course. (iii) Create a respectful and productive learning environment. (iv) Assess inclusive learning by paying attention to patterns of student learning and by feedback from the students about their learning experience. More details are available on the internet.

### Need of regular revision of course content

In view of the rapid growth of the subject of genetics in the 21$^{st}$ century, there is a need for regular revision of the course contents of the genetics courses prescribed both in schools and also for undergraduate and post-graduate students. The course content should also shift from describing simple Mendelian ratios involving 1-3 genes to complex quantitative traits, and this change in emphasis should start right from the beginning of a course in genetics, particularly at the post-graduate levels in the universities (Redfield 2012). Courses should be designed around the principle of 'active learning' and 'backward design', keeping in mind the latest developments in the field of genetics. In other words, the teachers should first formulate learning goals, and list what the student is supposed to be able to do after the course is over. Keeping this in mind, the courses should be formulated. This exercise should be undertaken periodically on a regular basis (Smith and Wood, 2016).

### References

Bowling B. V. et al. 2008. Development and evaluation of a genetics literacy assessment instrument for undergraduates. In (Ed. Pukkila P. J.). Genetics Education: Innovations in Teaching and Learning Genetics. Genetics, **178**: 15-22.

Brink R. A. and Cooper D. C. 1935. The association of semi-sterile 1 in maize with two linkage groups. Genetics, **16**: 595-628.

Chattopadhyay A. 2005. Understanding of genetic information in higher secondary students in Northeast India and the implications for genetics education. Cell Biology Education, **4**: 97-104.

Creighton H. B. and McClintock B. 1931. A correlation of cytological and genetical crossing over in *Zea mays*. Proc Nat'l. Acad. Sci. Washington, **17**: 492-497.

Endo T. R. and Gill B. S. 1996. The deletion stcocs of common wheat. J. Heredity, **87**: 295-307.

Gupta P. K., Chaudhary B. and Gheysen G. 2015. Removing Bt egg plant from the face of Indian regulators. Nature Biotech., **33**: 904-907.

Hake R. R. 1998. Interactive engagement *vs.* traditional methods: A six thousand-students survey of mechanics test data for introductory physics courses. Am J. Phys., **66**: 64-74.

Haldane J. B. S. 1919. The combination of linkage values, and the calculation of distance between linked factors, J. Genetics, **8**: 299-309.

Handelsman J. et al. 2004. Scientific teaching. Science, **304**: 521-522.

Handelsman J., Miller S. and Pfund C. 2007. Scientific Teaching. The Wisconsin Program for Scientific Teaching; W. H. Feeman & Co., New York.

Hawley R. S. 2012. The other life of articles. Genetics, **191**: 1029.

Huehn H. 2010. Random variability of map distances based on Kosambi's and Haldane's mapping functions, J. Appl. Genet., **51**: 27-31.

Infante-Malachias M. E. et al. 2010. Comprehension of basic genetic concepts by Brazilian undergraduate students. Revista Electrónica de Enseñanza de las Ciencias, **9**: 657-668.

Karagoz M. and Cakir M. 2011. Problem solving in genetics: conceptual and procedural difficulties. Educational Sciences: Theory and Practice, **11**: 1668-1683.

Kharakwal M. C. and Mehra R. B. Eds. (2001). "National Syllabus of Genetics and Plant Breeding" Indian Soc. Genet. & Pl. Breeding, IARI, New Delhi.

Khush G. S. and Rick C. M. 1968. Cytogenetic analysis of the tomato genome by means of induced deficiencies. Chromosoma, **23**: 452-484.F.

Kilic D., et al. 2016. A cross-national study of students' understanding of genetics concepts: implications from similarities and differences in England and Turkey. Educat. Res. Internl., **2016**: 1-14

Kosambi D. D. 1944. The estimation of map distance from recombination values, Annals Eugen., **12**: 172-175.

Lee, J. J. et al. 2018. Gene discovery and polygenic prediction from a genome-wide association study of educational attainment in 1.1 million individuals.

Nature Genetics, **50**: 1112-1121.

Lewis E. B. 1951. The phenomenon of pseudoallelism and gene evolution. Cold Sp. Harb. Symp., **16**: 159-172.

Lewis J. and Wood-Robinson C. 2000. Genes, chromosomes, cell division and inheritance—do students see any relationship? Int. J. Sci. Educ., **22**: 177-195.

Lewis J., Leach J. and Wood-Robinson C. 2000a. Chromosomes: the missing link—young people's understanding of mitosis, meiosis, and fertilization. J. Biol. Educ., **34**: 189-199.

Lewis J., Leach J. and Wood-Robinson C. 2000b. All in the genes?—Young people's understanding of the nature of genes. J. Biol. Educ., **34**: 74-79.

Lewis J., Leach J. and Wood-Robinson C. 2000c. What's in a cell?—Young people's understanding of the genetic relationship between cells, within an individual. J. Biol. Educ., **34**(3), 129-132.

Liu B. H., Statistical Genomics: Linkage, Mapping, and QTL Analysis, CRC Press, p.611, 1997.

Lock R. and Miles C. 1993. Biotechnology and genetic engineering: students' knowledge and attitude. J. Biol. Educ., **27**(4): 267-272.

Lock R., Miles C. and Hughes S. 1995. The influence of teaching on knowledge and attitudes in biotechnology and genetic engineering contexts: implications for teaching controversial issues and the public understanding of science. Sch. Sci. Rev., **76**: 47-59.

Longden B. 1982. Genetics—are their inherent learning difficulties? J. Biol. Educ., **16**: 135-140.

Marbach-Ad G. 2001. Attempting to break the code in students' comprehension of genetic concepts. J. Biol. Educ., **35**: 183-189.

Marbach-Ad G. and Stavy R. 2000. Student's cellular and molecular explanation of genetic phenomena. J. Biol. Educ., **34**: 200-205.

McClintock B. 1931. The order of the genes *C, Sh* and *Wx* in *Zea mays* with reference to cytologically known point in the chromosome. Proc. Nat'l. Acad. Sci. USA, **17**: 485-491.

Michie S. et al. 1995. A comparison of public and professional attitudes towards genetic developments. Pub. Und. Sci., **4**: 243-253.

Ponder M. et al. 1996. Family history and perceived vulnerability to some common diseases: a study of young people and their parents. J. Med. Genet., **33**: 485-492.

Pontecorvo G. 1958. *Trends in Genetic Analysis,* Columbia Univ Press/Oxford University Press, New York/London.

Radick G. 2016. Teach students the biology of their times. Nature, **533**: 293-293.

Redfield R. J. 2012. Why do we have to learn this stuff-a new genetics for 21$^{st}$ century students. PLoS Biol., **10**: e1001356.

Scriver C. R. 1993. Human genetics: school yard experiences. Amer J. Hum. Genet., **52**: 243-245.

Sears E. R. 1954. The Aneuploids of Common Wheat. Univ. Mo. Agric. Exp. Stat. Bull., **572**: 1-58.

Shaw K. R. et al. 2008. Essay contest reveals misconceptions of high school students in genetics content. Genetics, **178**: 1157-1168.

Smith M. K., et al., 2008. The genetics concept assessment: A new concept inventory for gauging student understanding of genetics. CBE Life Sci. Educ., **7**: 422-430.

Smith M. K. and Knight J. K. 2012. Using the Genetics Concept Assessment to document persistent conceptual difficulties to undergraduate genetics courses. Genetics, **191**: 21-32.

Smith M. K. and Wood W. B. 2016. Teaching genetics: past, present and future. Genetics, **204**: 5-10.

Stern C. 1931. Zytologische-genetische Untersuchungen als BeWeise fur Morgansche Theorie des Faktoraustauschs. Biol. Zbl., **51**: 547-587.

Wood W. B. 2004. Clickers: a teaching gimmick that works. Dev. Cell, **7**: 796-798.

Wood-Robinson C. 1994. Young peoples' ideas about inheritance and evolution. Stud. Sci. Educ., **24**: 29-47.

Wood-Robinson C. 1995. Childrens' biological ideas: knowledge about ecology. Inheritance and evolution. Learning science in the schools. In Glynn, S. M. and Duit, R. Research Reforming Practice. Lawrence Erlbaum Assoc. Mahwah, N.J.

Wood-Robinson C., Lewis J. and Leach J. 2000. Young people's understanding of the nature of genetic information in the cells of an organism. J. Biol. Educ., **35**(1): 29-36.