Biscene

Journal of College Biology Teaching

Volume 27(2) May 2001

Bioscene

Journal of College Biology Teaching

Volume 27(2) May 2001

A Peer-Reviewed Journal of the

Association of College and University Biology Educators

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An archive of all publications of the Association of College and University Biology Educators (ACUBE) can be found at http://acube.org

Bioscene is normally published in March, May, August and December. Please submit manuscripts by July 1, 2001 for consideration in the next issue.

Cover image: .View of a cypress swamp along the Mississippi River near Vicksburg, MS. Photograph by Timothy Mulkey.

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Bioscene: Journal of College Biology Teaching

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Deadlines for Submissions

July 1, 2001 for the August 2001 Issue **November 1, 2001 for the December 2001 Issue**

Incorporating Techniques of Molecular Genetics into the Developmental Biology Laboratory Curriculum: Modeling the Current State of the Field

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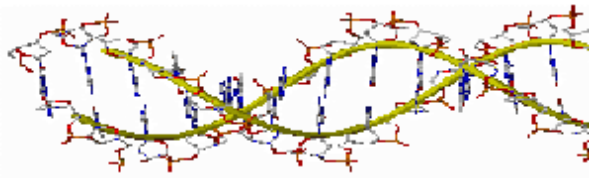
Abstract: Technological advances in molecular genetics have had a major impact on the field of developmental biology. Using modern molecular techniques, developmental biologists now study how differential gene expression directs organogenesis in the developing embryo. In order for students to experience firsthand the power of molecular techniques to developmental biologists, I incorporated a gene expression unit into my developmental biology laboratory course. In this unit, students learn fundamental techniques in molecular genetics and use them to examine changes in gene expression during embryogenesis. They isolate RNA from embryonic tissue, detect the expression of specific mRNAs in that tissue by performing the reverse transcriptase - polymerase chain reaction (RT-PCR), and analyze their RT-PCR products by performing gel electrophoresis. Initially, this unit was approached by providing students with a specific, well-characterized gene to study. However, recently the unit has been conducted with a research-based learning approach, in which students formulate and test a novel hypothesis using the same techniques. The benefits and potential pitfalls of each approach are discussed. Potential applications of gene expression units in other laboratory courses are also discussed.

Keywords: developmental biology, molecular genetics, research-based learning approach, inquiry, reverse transcriptase - polymerase chain reaction (RT-PCR)

INTRODUCTION

The field of developmental biology has a magnificent embryological heritage. Using classic anatomical approaches, early embryologists provided us with a remarkably detailed picture of the morphological changes that take place as a single fertilized egg is transformed into a living, breathing organism. Our fundamental understanding of the events that take place between fertilization and birth are based on the findings of their studies. It is important, then, that an undergraduate laboratory course in developmental biology reflects this heritage, and provides students with the opportunity to engage in classic embryological studies.

Equally important is the opportunity for students to experience the recent impact of molecular genetics on the field of developmental biology. Technological advances in the field of molecular genetics have provided developmental biologists with the tools to examine how differential gene expression directs organogenesis. No longer are developmental biologists content to just study the anatomical changes that take place during embryogenesis; they want to know how the genome directs this complex series of events. As such, developmental biologists routinely employ molecular techniques in their laboratory investigations: they use the reverse transcriptase - polymerase chain reaction (RT-PCR) and *in situ* hybridization to detect and quantitate gene expression in the developing embryo; they use transgenic and knockout animal models to determine the impact of overexpression or removal of a gene on specific developmental processes; and they screen cDNA libraries in search of novel genes that play a critical role during development.



In order for undergraduate students to experience firsthand the power of molecular techniques for the developmental biologist, I incorporated a gene expression unit into my developmental biology laboratory curriculum (see Table 1 for a laboratory syllabus). In this unit, students use fundamental techniques in molecular genetics (RNA extraction, RT-PCR, gel electrophoresis) to analyze temporal changes in gene expression in a developing tissue. The unit takes place over a three-week period, with students participating in one three-hour laboratory session per week. The students enrolled in the course are typically third or fourth year biology majors who have already completed a course in genetics.

Table 1: Developmental Biology Laboratory Syllabus.

Week	Laboratory Description
1	Review of Microscopy
2	Gametogenesis (slide lab)
3	Echinoderm Fertilization I
4	Echinoderm Fertilization II
5	Lab Practical I
6	Whole Mount Chick Embryos (slide lab)
7	Organogenesis in the Chick (slide lab)
8	Staging of Live Chick Embryos
9	Lab Practical II
10	Embryonic Cell Culture I
11	Embryonic Cell Culture II
12*	***Preparation of RNA from Staged Mouse Embryos***
13*	***Developmental Regulation of Gene Expression (RT-PCR)***
14*	***Electrophoresis; Analysis of RT-PCR Results***

**Laboratories that are part of the gene expression unit.*

Topics for Gene Expression Units: "Cookbook" vs. Inquiry-Based Approach

Initially, the gene expression unit was taught with a "cookbook" approach; students were provided with a specific, well-characterized gene to study and they knew what the outcome of the experiment would be (barring any technical problems). The gene of interest was the pit-1 gene, which encodes a pituitary-specific transcription factor that directs the differentiation of anterior pituitary cells into somatotrophs (growth hormone-producing cells), lactotrophs (prolactin-producing cells) and thyrotrophs (thyroid-stimulating hormone-producing cells) during embryogenesis (reviewed in Gilbert, 1997). Pit-1 was originally chosen as the focus of our laboratory unit on gene expression for two reasons. First, pit-1 gene expression is tissue-specific. This characteristic permits simple, rough dissections of embryos to obtain the tissue of interest. Since no other tissues express pit-1 mRNA, there is no need for concern about contamination by others tissues (e.g., the brain) interfering with the results. Second, pit-1 serves as an excellent example of a developmentally-regulated gene. Pit-1 transcripts first appear in the developing mouse pituitary gland (Rathke's pouch) on embryonic day 16 which is 2-3 days prior to the onset of growth

hormone gene expression (Dolle et al., 1990; Simmons et al., 1990) and continue to be expressed into adulthood. By comparing pit-1 gene expression (or lack thereof) in day 15 embryos to that observed in day 17 embryos, students gain an appreciation of the precise, temporal regulation during development of genes involved in the differentiation process. To make the laboratory unit more challenging, students are provided with their tissue samples in unmarked tubes (simply labeled as tube A and tube B), and based on the results of their RT-PCR analyses, they are to tell me which tube contained the embryonic day 15 sample and which contained the day 17 sample.

In recent years, I've taken an inquiry-based approach to the gene expression unit, in which students work together to formulate a novel hypothesis and then test it in the lab using the RT-PCR technique. The decision to take an inquiry-based approach to the unit was a logical extension of classroom discussions that centered on current scientific papers in the field of developmental biology. During these discussions, students are often encouraged to formulate specific hypotheses that build upon the results of the studies. In the past two years, I have "guided" these discussions so that they culminate in a hypothesis that can easily be tested in the lab during our gene expression unit. One year, we determined whether a human placental cell line expresses a particular transmembrane receptor that is believed to play a role in the regulation of human chorionic gonadotropin (hCG or pregnancy hormone) production; another year, we examined whether the rat ovary expresses a specific transmembrane receptor that is believed to play a role in folliculogenesis. Providing students with the opportunity to test their novel hypotheses in the laboratory adds greatly to the enthusiasm with which students approach the gene expression unit. Student feedback at the end of the semester indicated that the inquiry-based approach gave them a better feel for ***what it is really like to conduct research***. They also greatly appreciate the continuity between specific topics discussed in lecture and experiments carried out in the laboratory.

It should be noted that the inquiry-based approach to the gene expression unit -- like any scientific experiment - carries with it the risk that the student investigators will obtain negative results. If the novel gene is not expressed in the tissue of interest, then students will obtain no PCR product. Such results may lead students to question whether they have obtained a true negative result or whether their lack of PCR product is due to technical problems (e.g., RNAse contamination of RNA samples). To eliminate this uncertainty, it is essential that students be encouraged to include one or more positive control in their experiments. This could include performing an additional PCR reaction to amplify a cDNA that is known to be expressed at high levels in the tissue of interest (e.g., those that encode cytoskeletal proteins such as α-tubulin or β-actin). Alternatively, if cost prohibits the purchase of another set of PCR primers, students can isolate RNA from an additional tissue that is known to express the transcript of interest at high levels. Students can then perform an RT-PCR reaction with RNA from this positive control tissue to confirm that their experimental technique is sound.

Materials and Methods For Gene Expression Unit

Week 1

During the first week of the gene expression unit, students extract RNA from the tissue of interest (e.g., mouse embryos). If the gene expression unit involves the pit-1 project described above, I purchase timed pregnant female mice from Charles River Laboratories (Wilmington, MA) approximately one month prior to the start of the unit. On the appropriate day of gestation, the pregnant females and embryos are euthanized and a sample of tissue (50-100 mg in weight) that includes the developing pituitary gland is excised from the anterior region of the embryos. Each tissue sample is immediately frozen by placing it in a labeled microcentrifuge tube that is packed in dry ice. When the samples are frozen, the tubes are placed in a -80^{o}C freezer until the RNA extractions are performed. In the past, I have not included the embryonic dissections as a required part of the laboratory exercise, since some students prefer not to participate in this aspect of the experiment. Rather, I set up a time outside of the regularly scheduled laboratory period during which I perform the dissections along with students who are interested in participating. If the gene expression unit involves the isolation of RNA from cultured cells, approximately 5-10 x 10^6 cells are required per sample.

To extract RNA from the tissue(s) of interest, I employ a method of RNA isolation that involves the use of TRI reagent (Molecular Research Center, Inc), a commercially available solution that lyses cells and separates nucleic acids from proteins. See Table 2 for a list of the materials and pieces of equipment needed to perform RNA extraction using TRI reagent. At the start of the first laboratory period of the unit, students are given microcentrifuge tubes containing their samples stored on ice. Prior to the start of the laboratory procedure, I alert students to the abundance of RNAses on their skin and on airborne dust particles, bacteria and molds. I emphasize the importance of using RNAse-free procedures throughout the laboratory period in order to ensure that their RNA sample is not degraded during the extraction procedure. RNAse-free procedures include wearing gloves at all time, using sterile microcentrifuge tubes and pipette tips, and using water and solutions that have been treated with diethylpyrocarbonate (DEPC), a chemical that destroys RNAses. They then begin the RNA

extraction procedure by adding 1 ml of TRI reagent solution to their sample tubes. The samples are then homogenized and the homogenate is incubated at room temperature for 15 minutes. Next, 0.2 ml of chloroform is added to each sample. The microcentrifuge tubes are capped, mixed vigorously and stored at room temperature for 10-15 minutes. Following the room temperature incubation, samples are placed in a microcentrifuge maintained at 4°C and spun at 12,000g for 15 minutes.

Table 2: Materials and Equipment Needed for RNA Extraction Laboratory (Week 1)

Frozen tissue explants or cultured cells on ice
TRI Reagent (for tissue explants) or TRI Reagent LS (for liquid samples of cultured cells)
Sterile microcentrifuge tubes (1.5 ml), sterile pipette tips, gloves
Micropipettors (for volumes between 20 and 1000 µl)
Microcentrifuge maintained at 4°C
Chloroform
Isopropanol
75% ethanol
DEPC-treated water
Water bath maintained at 55°C
Agarose
1X Tris – borate – EDTA (TBE) buffer
Ethidium bromide staining solution (1 mg/L water)
Electrophoresis equipment for minigel(s)
Loading dye
UV transilluminator with camera, film and protective eyewear
UV spectrophotometer

At this point, three layers will be visible in each sample: a bottom phase and middle phase containing mostly DNA and proteins and a colorless, aqueous phase at the top that contains RNA. The top aqueous phase will be approximately 60% of the original sample volume (about 600 µl). Students are instructed to set their pipette volumes at 600 µl and carefully remove the top phase from their samples. The top phase is placed in a new, sterile microcentrifuge tube and the RNA is precipitated by adding 0.5 ml isopropanol to the tubes. The tubes are capped, mixed vigorously, and stored at room temperature for 10 minutes. The precipitated RNA will not be visible at this point. Following the 10 minute incubation, the tubes are placed in a microcentrifuge maintained at 4°C and spun at 12,000g for 10 minutes to pellet the precipitated RNA.

After the centrifugation, a gel-like RNA pellet will be visible on the side and bottom of each tube. Often, students have difficulty locating the pellets and assistance from the instructor is required. It is easiest to locate the pellet when the microcentrifuge tubes are held up to a light source. When students have verified the presence of pellets in their tubes, they open them and carefully decant the isopropanol. Then, for a final wash of the RNA pellets, 1 ml of 75% ethanol is added to each tube. The tubes are capped and briefly vortexed to lift the pellets off of the sides of the microcentrifuge tubes. There is no need to resuspend the RNA pellets at this point. A final centrifugation is conducted at 12,000g for 5 minutes at 4°C. Again, RNA pellets will be visible on the sides and/or bottoms of the tubes after centrifugation. The 75% ethanol is carefully decanted from each tube, and the tubes are then placed in an ice bucket with the tops open to allow the pellets to air dry.

When the RNA pellets have dried sufficiently, 20 µl of DEPC-treated water is added to each tube and each pellet is gently resuspended using a micropipettor with a sterile pipette tip. If the pellets do not go completely back into solution, the tubes may be placed in a 55°C water bath for about 10 minutes to facilitate the process. Afterwards, RNA concentrations are measured using a UV spectrophotometer. To perform these measurements, one microliter of each sample is diluted 1:100 with sterile water and absorbance readings are taken at a wavelength of 260 nm.

Finally, students must verify the integrity of their final RNA samples. This is accomplished by running a 27 µl fraction of the 1:100 dilution (saved from the spectrophotometer measurements) on a 1% agarose gel in 1X TBE buffer. Prior to loading the 27 µl aliquots of RNA samples on the gel, 3 µl of loading dye are added to each sample. After electrophoresis, the gels are stained with ethidium bromide (15 minutes in a 1 mg/L solution) and ribosomal RNA bands are visualized using a UV transilluminator. Photos for student lab notebooks may be taken if a camera is available. As illustrated in Figure 1, distinct bands of ribosomal RNA should be visible on the gel if RNA integrity has remained intact. If distinct bands are not present, but rather a smear appears down the lane of the gel, this indicates that degradation of the RNA sample has occurred, probably due to RNAse contamination of samples. Thus far, I have not experienced a problem with RNAse contamination of samples when performing this laboratory exercise with students.

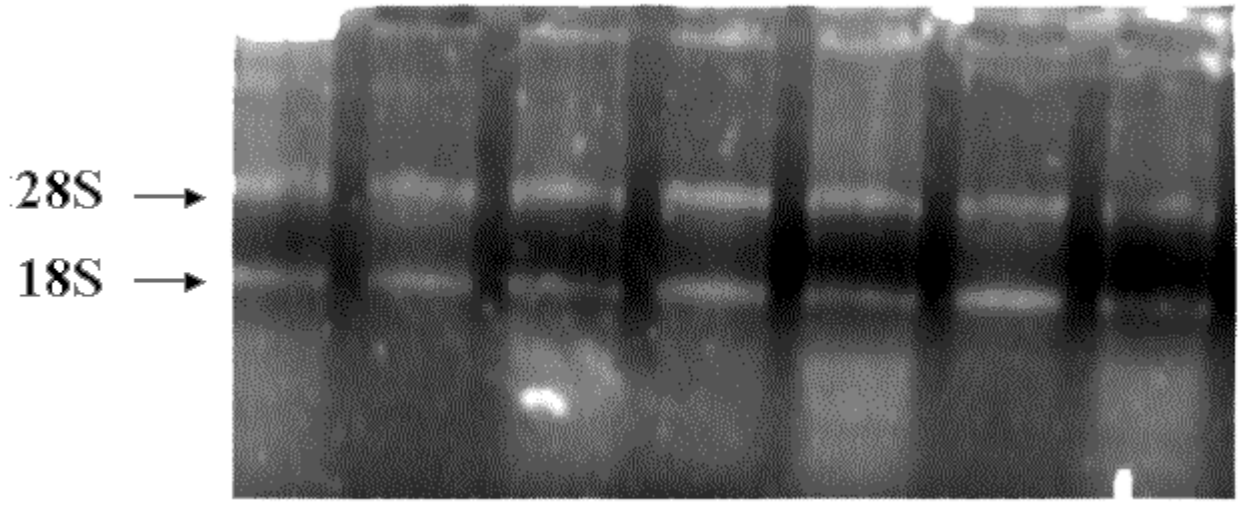


***Figure 1**: **Ribosomal RNA bands in total RNA extracted from a choriocarinoma cell line.** Students isolated RNA using the TRI reagent method and visualized the ribosomal RNA bands on a 1%, ethidium bromide-stained agarose gel.*

At the end of the week 1 laboratory period, RNA samples are stored in a –80°C freezer until RT-PCR is performed during the week 2 laboratory period. At this point, I also encourage students to read background material describing the RT-PCR technique prior to attending next week's lab.

Contamination of RNA samples with genomic DNA does occasionally occur. Genomic DNA contamination of RNA samples can prove problematic during the RT-PCR exercise in that PCR primers will bind to complementary sequences in genomic DNA (in addition to binding to complementary sequences in cDNA that were reverse transcribed from RNA) and generate PCR products, potentially leading to false positive PCR results. To help students distinguish between PCR products amplified from genomic DNA vs. cDNA reverse-transcribed from RNA, I design PCR primers to span an intron in the sequence of the gene of interest. In so doing, any PCR products amplified from genomic DNA will be much larger than PCR products generated from primers binding to cDNAs.

Week 2

The 2nd laboratory period of the gene expression unit involves performing RT-PCR reactions to detect the expression of the mRNA(s) of interest in student samples. Prior to performing the RT-PCR technique, I spend a significant amount of time reviewing the procedure with students to ensure that 1) they understand how the technique allows for the detection of mRNA expression in the tissue(s) of interest; and 2) they understand the power of the technique for researchers (such as developmental biologists) who are interested in detecting gene expression in very small quantities of tissue.

The materials and equipment needed for week 2 of the gene expression unit are listed in Table 3. All RT-PCR reagents (AMV reverse transcriptase with buffer, random hexamers, nucleotide mix, and Taq DNA polymerase with buffer and $MgCl_2$) are available through Promega Corporation (Madison, WI). Oligonucleotide primers can be purchased from Life Technologies (Rockville, MD).

Table 3: Materials and Equipment Needed for RT-PCR Laboratory (Week 2)

RNA samples (from week 1) on ice
AMV reverse transcriptase with buffer
Random hexamers (500 μg/ml)
Deoxynucleotide mix (10 mM of each dNTP)
Sterile water
PCR tubes and tube racks
Taq DNA polymerase with buffer and $MgCl_2$
PCR oligonucleotide primers (complementary to cDNA of interest and positive control cDNA)
Mineral oil
Micropipettors with tips
Thermocycler
Microcentrifuge
Ice buckets

To set up the reverse transcription reaction, students are instructed to add the following reagents to a PCR tube:

1.0 μg RNA (isolated during week 1)
1.0 μl random hexamers (500 μg/ml)
2.0 μl deoxynucleotide mix (10 mM)
2.0 μl 10X AMV reverse transcriptase buffer
1.5 μl AMV reverse transcriptase

Students then add sterile water to the RT reaction to bring the final volume to 20 μl. After a 10-minute incubation period at room temperature (to allow random hexamers to anneal to RNA), the samples are placed in a PCR machine for a 15-minute incubation at 42°C (for reverse transcription of RNA into cDNA) and a 5-minute incubation at 99°C (to inactivate the RT and degrade the RNA).

After students have performed reverse transcription reactions for each RNA sample, they are ready to proceed with PCR reactions to amplify their cDNA(s) of interest. At this point, students are provided with oligonucleotide primers (18-20 bases in length) that will amplify a ~300 basepair (bp) fragment of their target cDNA (e.g., pit-1). If students are to be provided with an additional set of oligonucleotide primers for amplification of an abundant, positive control cDNA (e.g., alpha-tubulin), primers are designed to amplify a cDNA fragment that is ~500 bp in length. The size difference between products generated by the two sets of PCR primers allows for coamplification within the same PCR tube, since the two products will be readily distinguished from one another when separated by gel electrophoresis. See Table 4 for sequences of primers used to amplify mouse alpha tubulin and mouse pit-1 cDNAs when performing the pit-1 gene expression unit.

To set up the PCR reaction, students are instructed to add the following reagents to a fresh PCR tube on ice:

10 μl RT product
10 μl 10X Taq DNA polymerase buffer
4 μl $MgCl_2$ (25 mM)
2 μl pit-1 (or other) 5' primer (20 pmol/μl)
2 μl pit-1 (or other) 3' primer (20 pmol/μl)
2 μl α tubulin 5' primer (20 pmol/μl)
2 μl α tubulin 3' primer (20 pmol/μl)
1 μl Taq DNA polymerase
67 μl sterile water

After capping the reaction tubes and mixing briefly, students reopen the tubes and overlay their samples with 100 μl of mineral oil to prevent evaporation of samples during thermocycling. Then, the samples are handed in to the instructor, who places them in a programmable thermocycler. If students are amplifying pit-1 and α-tubulin cDNAs, the thermocycler is programmed to undergo 30 cycles under the following reaction conditions: denaturation at 94 C for 1 minute, annealing at 55 C for 1 minute, and extension at 72 C for 1 minute. Optimal reaction conditions may vary for other primers used in the PCR reactions.

Table 4: Sequences of PCR Oligonucleotide Primers Used in Pit-1 Gene Expression Unit

Primer	Sequence
Mouse α tubulin 5' primer	5'-CGTGTCACTACACCATTG-3'
Mouse α tubulin 3' primer	5'-CTCAGCAGAATGACAGCG-3'
Mouse pit-1 5' primer	5'-TGCCCTGCCTCTGAGAAT-3'
Mouse pit-1 3' primer	5'-TTTCCGCCTGAGTTCCTG-3'

Week 3

During the final laboratory period of the gene expression unit, students perform gel electrophoresis to detect the presence of PCR products in their samples. Prior to attending lab that day, students read background material on gel electrophoresis and draw sketches in their laboratory notebooks of the expected appearance of their PCR products on the agarose gel. For example, if the students are conducting the pit-1 project, they would predict the appearance of a 300 bp band of pit-1 cDNA in the sample obtained from the day 17 but not the day 15 embryo. Furthermore, the students would predict the appearance of the 500 bp α-tubulin cDNA in both the day 17 and the day 15 samples.

The materials needed for the last laboratory period of the gene expression unit are listed in Table 5. The loading dye and PCR markers (DNA ladder) are available through Promega Corporation (Madison, WI).

When students arrive at lab on the last day of the gene expression unit, they prepare a 1% agarose gel in TBE buffer for separation and visualization of PCR products (Figure 2). After the gels have been cast, students prepare 27 µl aliquots of their PCR products (plus 3 µl of 10X dye) for loading onto the agarose gel. Students also prepare 5 µl aliquots of PCR markers (along with 0.5 µl of loading dye) to load on the gel for estimating the sizes of their PCR products. After electrophoresis of samples, students stain their gels in an ethidium bromide solution and visualize the stained bands with a UV transilluminator. Each student then takes a photograph of the gel to place in his/her laboratory notebook. See Figure 3 for an example of PCR results generated during an inquiry-based gene expression unit in Developmental Biology.

Table 5: Materials and Equipment Needed for Electrophoresis Laboratory (Week 3)

PCR samples
Electrophoresis equipment for minigels
Agarose
1X TBE buffer
Ethidium bromide solution (1 mg/L water)
10X loading dye
PCR markers (50-1,000 bp)
Micropipettors with tips
Microcentrifuge tubes (1.5 ml), tube racks, and gloves
UV transilluminator with camera, film and protective eyewear

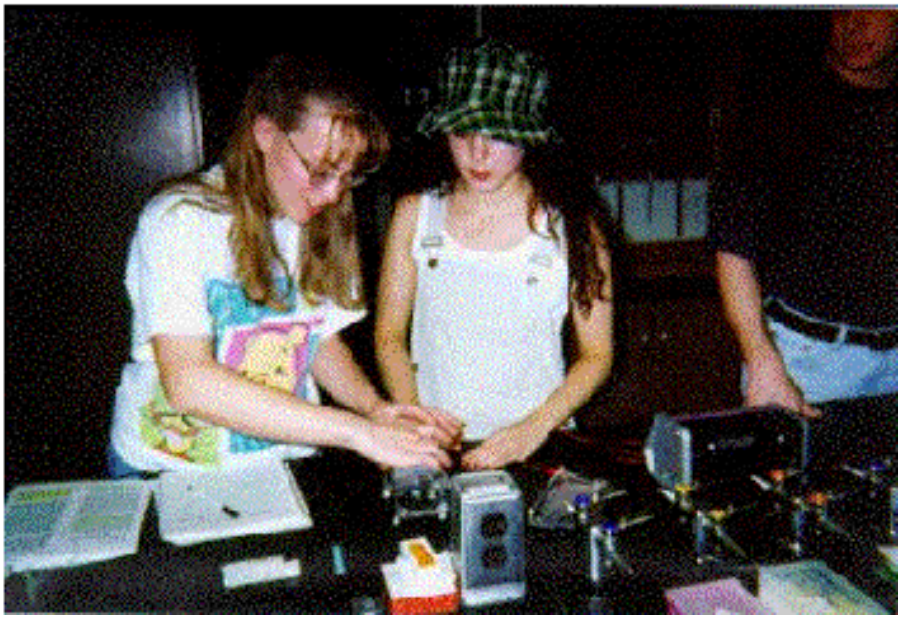


Figure 2**: **Developmental biology students perform gel electrophoresis of PCR products.

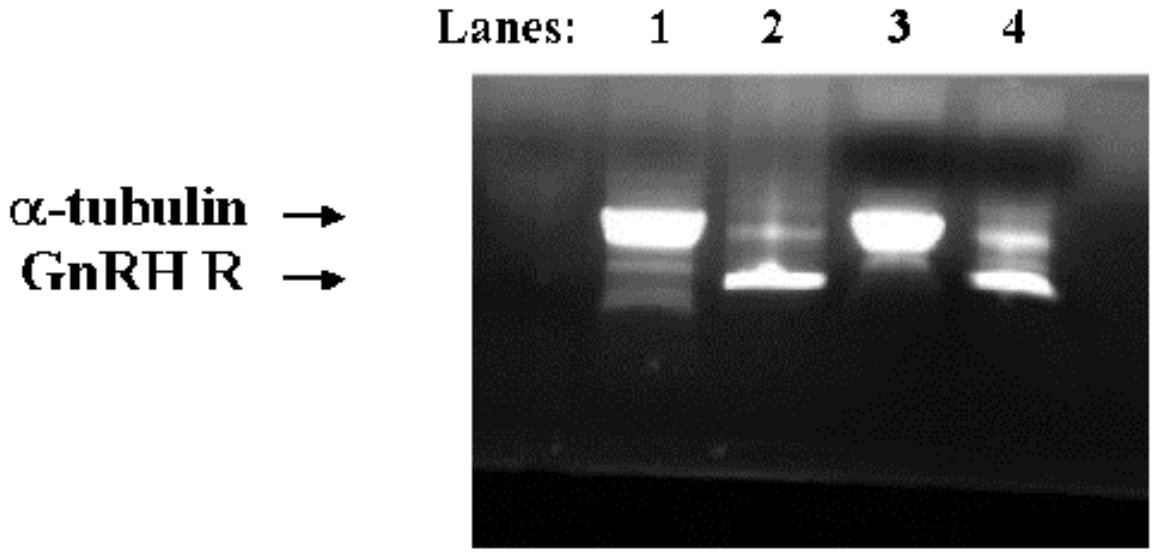


Figure 3: Student PCR results from an inquiry-based gene expression unit. *Students analyzed gonadotropin-releasing hormone receptor (GnRH R) mRNA expression (lanes 2 and 4) and α-tubulin mRNA expression (positive control; lanes 1 and 3) in a choriocarcinoma cell line.*

The remainder of the laboratory period is devoted to a discussion of results. Students are asked to comment on the expected vs. actual appearance of their PCR products (experimental and control) on the stained gel. If students conducted the pit-1 project and didn't observe the presence of pit-1 cDNA (or possibly even α-tubulin cDNA) in either sample, they are asked to comment on possible experimental errors that may have contributed to their lack of results. If the students conducted an inquiry-based project and obtained negative results, they are asked to explore alternative hypotheses regarding the expression of the gene of interest. If the students obtained positive results when conducting an inquiry-based project (by far the most exciting scenario!), they are encouraged to think about possible future experiments to build upon their novel findings. This "wrap-up" discussion is helpful in preparing students write a final laboratory report that summarizes their research activities during the gene expression unit.

Conclusions

The project summarized in this paper has proven to be a valuable tool for teaching students the ways in which developmental biologists utilize molecular techniques to study developmental events. After conducting the gene expression unit, students report that they have a greater appreciation for the enormous impact that recent advances in molecular genetics have had on the field of developmental biology. Furthermore, when the gene expression unit is introduced within the context of a well-rounded developmental biology laboratory curriculum, it provides students with a historical perspective of the field and an appreciation for the early work of embryologists; they learn how early anatomical studies laid the foundation for current investigations into the genomic mechanisms that direct morphogenesis.

Developmental biology is not the only field that has been revolutionized by advances in molecular genetics. Neurobiologists, immunologists, reproductive biologists, and others have gained an enormous amount of information about their system of interest by employing molecular techniques in their studies. As such, the gene expression unit described in this paper has a number of potential applications in other undergraduate courses in addition to developmental biology. For example, a colleague of mine who is a nutritionist is currently revising the gene expression unit for use in a nutritional biochemistry course. The revised unit will allow nutritional biochemistry students to assess the impact of excess nutrients (or a deprivation of nutrients) on the expression of specific genes in vascular smooth muscle.

In conclusion, inclusion of the project described in this paper in the developmental biology laboratory curriculum has proven to be an effective method for introducing students to the power of molecular techniques for the developmental biologist. Conducting the project with a research-based approach has further enhanced the impact of the gene expression unit on student learning. The students become familiar with the scientific method as they construct their own hypotheses regarding gene expression during embryonic development, and design and carry out experiments in the laboratory for testing these hypotheses.

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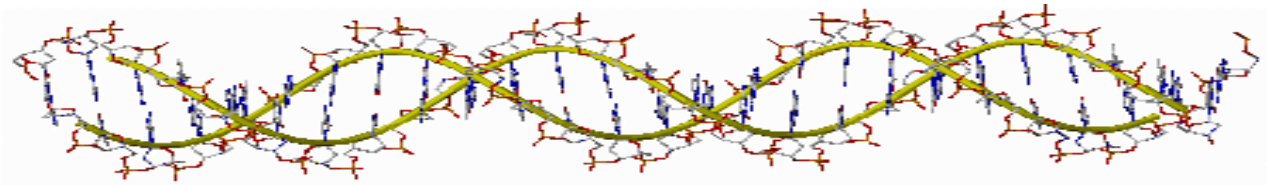

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The "Rediscovery" of Mendel's Work

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Abstract: Contrary to popular belief, Mendel's famous paper about plant breeding announced no major findings; it was known and acknowledged as "typical" science for its day. When it was "rediscovered" in 1900, Mendel's paper became famous primarily as a result of a priority dispute between de Vries and Correns. This dispute prompted researchers to reinterpret and read importance into Mendel's paper.

***Keywords*:** Correns, de Vries, Genetics, Mendel, Tschermak

"Mendel's 1865 report ... fell on deaf ears". (Lander and Weinberg, 2000)

"There is not known another example of a science which sprang fully formed from the brain of one man." (de Beer, 1965)

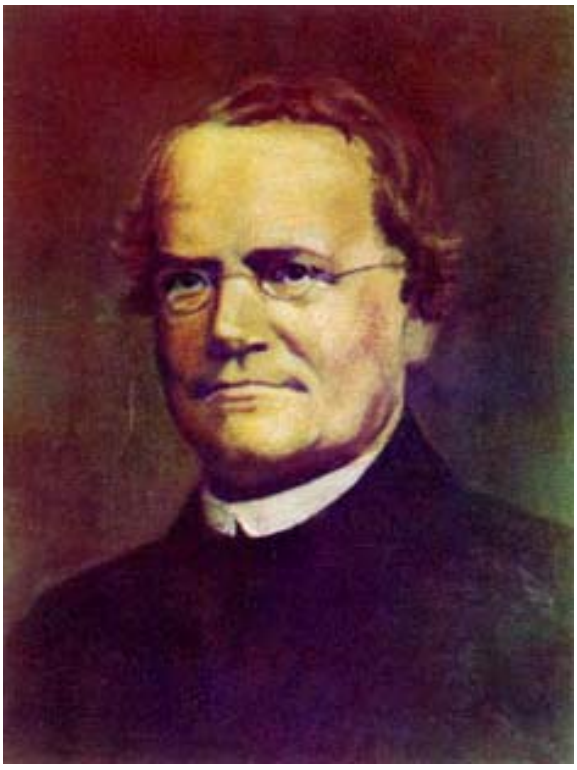
"The publication of Mendel's paper in 1865 [sic] was the throwing of pearls before swine." (Darbishire, 1911)

"All geneticists admitted that [Mendel's paper] was written so perfectly that we could not – not even at present – put it down more properly … It was a work which came prematurely but being repeated and rediscovered it became one of the immortal works of the human spirit penetrating into the mystery of life" (Nemec, 1965)

"Stolidly the audience had listened … Not a solitary soul had understood him. Thirty-five years were to flow by and the grass on the discoverer's grave would be green before the world of science comprehended that tremendous moment." (Eiseley, 1959)

"[Mendel's] laws were read back into his work and have continued to be read back in textbooks ever since". (Bennett, 1964)

"Mendelian historiography is a continuing detective story where overstatement and misunderstanding seem to have been, and still are the fashion of the day". (Meijer 1982)



Introduction

Gregor Mendel (1822-1884) ranks second only to Charles Darwin on most biologists' scales of hero worship. Mendel has been credited with discovering the first two laws of inheritance (i.e., the laws of segregation and independent assortment), which form the basis of what is now called "Mendelian genetics." Consequently, Mendel -- like Darwin -- is included in

all courses in introductory biology; he is said to have provided the foundation of genetics, supplied the missing mechanism in the Darwinian revolution, and, in the process, changed our understanding of the world (Gliboff, 1999; Olby, 1979).

Discussions of Mendel's work are almost always accompanied by mythical stories of how Mendel's discoveries were rejected and how he died neglected, only to be resurrected as a scientific genius. Mendel's resurrection involved a "rediscovery" of his work by botanists Carl Erich Correns (1864-1933) of Tübrgen (Germany), Erich Tschermak von Seysenegg (1871-1962) of Esslingen (near Vienna, Austria), and Hugo Marie de Vries (1845-1935) of Amsterdam (Netherlands), each of whom claimed to have independently rediscovered and independently published virtually the same results in early 1900 (i.e., 16 years after Mendel's death). As Tschermak (1900) himself claimed,

> "The simultaneous discovery by Mendel by Correns, by de Vries, and myself appears to me especially gratifying ..."

Many reasons have been given for the alleged neglect of Mendel's paper, including that it was not distributed to Mendel's contemporaries, that it was overshadowed by Darwin's work, that it was a "duplication of previous research," that it was based on a "forbidding mathematical approach," that it was "premature" and that "the time was not yet ripe" for Mendel's ideas, that it was done by an amateur scientist, and that it was published in an obscure journal (e.g., see Gliboff, 1999; Iltis, 1932; Gasking, 1959; Orel and Kupstor, 1982; Barber, 1961; and references therein). Some of these claims are true; for example, Mendel was an amateur scientist and he did publish his work in a relatively obscure journal. However, these facts alone do not validate the many claims that Mendel's work was unknown or neglected. Moreover, there is an alternate hypothesis; namely, that 1) Mendel's work was known and acknowledged as "typical" science that was not revolutionary when viewed in the context of its time (Olby, 1979), and 2) Mendel's work became famous not only for its content, but also as a result of a priority dispute among its "rediscoverers." In this paper, I will develop this alternate hypothesis.

Mendel's Paper

On 8 February and 8 March of 1865, Mendel described his research at consecutive monthly meetings of the Brünn Natural Science Society (Orel 1984).[1] Although the "Mendel mythology" claims that there were no questions or discussion after either presentation, the facts are different: both presentations generated "lively discussions" (e.g., see Henig 2000, Orel 1973, Olby and Gautrey 1968). Mendel's talks were received favorably and were reported in Brünn's daily newspaper (*Tagesbote*) and in Czech and German newspapers as contributions to hybridization (Brannigan 1981). The following year, Mendel (1866) published his now famous (but seldom read) 48-page paper in the society's journal of its proceedings, *Proceedings of the Brünn Society for the Study of Natural Science*. That paper reported research done by Mendel from 1854-1863 (after he abandoned his mice-breeding experiments) involving almost 28,000 plants, of which he "carefully examined" 12,835 plants.[2] Mendel's key experiments involved crossing two pure-breeding varieties of garden pea (*Pisum sativum*) that differed in easily distinguishable ways (e.g., the shape and color of seeds). Mendel confirmed his findings by testing his crosses through at least four generations.

About Mendel's paper:

- Mendel's paper was about speciation and hybridization, not heredity; it did not even include the words ***heredity*** or ***inheritance***. On the contrary, Mendel was trying to find "a generally applicable law governing the formation and development of hybrids." Similarly, the discussions following Mendel's presentations to the Brünn Natural Science Society in 1865 (see above) were about hybridization, not heredity. These results suggest that Mendel's contemporaries may have understood the purpose of Mendel's paper better than did those who "rediscovered" it in 1900 (Corcos and Monaghan, 1990).
- Mendel never mentioned the now-famous 9:3:3:1 ratio in his paper.
- Mendel often used italics to announce what he felt were important findings. For example, Mendel used italics to note that "*the behavior of each pair of differing traits in a hybrid association is independent of all other differences in the two parental plants".*
- This phrase – the climax of his paper -- would later be developed by the "rediscovers" and others into Mendel's Law of Independent Assortment. Contrary to numerous claims (e.g., that Mendel "discerned several fundamental laws of heredity"; Lander and Weinberg 2000), Mendel's paper announced no major discoveries and did not state any of "Mendel's laws." Those laws were proposed by Mendel's successors.
- Although Mendel's influence on biology is undeniable, the aims and results of his 1866 paper were not as grand as has sometimes been claimed (Simmons, 1996; Orel, 1996 and references therein).[3] Mendel's work includes no evidence that Mendel had any concept of particulate determiners, either paired or unpaired. Mendel never described the nature of

a gene, nor did he describe the equivalence between character pairs and pairs of factors of inheritance. In that regard, Mendel was not a Mendelian (see Olby, 1979). Correns, not Mendel, was the first to introduce the concept of equivalence.

- Mendel used the cell theory of fertilization to explain why some offspring of hybrids breed true and others do not (he wanted to "throw light on the composition of the egg cells and pollen cells in hybrids"). Mendel didn't use this theory to locate genes; he had no concept of genes, and his work does not mention two (and only two) mutually exclusive factors or elements in heredity. Mendel did discover the composition of egg and pollen cells, but he did so without invoking the idea of segregation or, for two or more traits, independent assortment. Mendel was studying the numbers and types of progeny produced by self-fertilized hybrids, not the inheritance of characters.
- Mendel used two different words that are both often translated as "character trait": but which, in fact, have different meanings. *Merkmal* refers to a feature that one can see or recognize; that is, a "trait." Mendel used *Merkmal* more than 150 times in his paper; in the "rediscovery" papers of 1900, this word often was translated as "factor" or "determinant." However, Mendel also used the word *Elemente*, which has a meaning similar to its English cognate, *element*; Mendel used *Elemente* to refer to unknown substances that might produce *Merkmal*. Mendel's 10 uses of *Elemente* were always plural and were restricted to his paper's conclusion, where he deduced elements from the way that traits had moved from one generation to the next. The 20th-century hindsight enjoyed by Mendel's rediscoverers may have prompted them to use more biologically-modern words (e.g., "factor") and, in the process, make it seem that Mendel was closer to the gene concept than he really was (see discussion in Henig 2000).
- Mendel was the first to describe hybrids with double letters (e.g., Aa), suggests he knew that hybrids carried two different character traits. However, he used only one letter for pure-breeding stocks (e.g., his description was A:2Aa:a). Perhaps Mendel believed that pure-breeding plants had only one such character, or, more likely, he may not have thought that his letters represented any sort of physical structure at all (e.g., see Henig 2000).
- Mendel explained his results mathematically as a "series." This enabled him to see the constancy of the various types of progeny, as well as that this constancy could be used to understand the results of his many different crosses. Although Mendel was one of the first biologists to use generalizations involving binomials and mathematical symbols, his work was not based on overly difficult math.
- Mendel's experiments involved 34 different seed-types that Mendel assumed were *Pisum sativum*, but there were probably other species as well (e.g., *P. quatratum*, *P. saccharatum*; see Henig 2000). Mendel wasn't overly concerned about their precise classification, noting that it was "just as impossible to draw a sharp line between species and varieties themselves." Mendel believed that this line was "quite immaterial" to his experimental goals; all he wanted was pure-breeding plants (Henig, 2000).

Mendel's contemporaries considered Mendel's work to be about hybridization, not heredity. For example, a letter by Iltis and Tschermak in 1907 to potential donors for a Mendel monument stated that "the discovery and actual determination of the hybridization laws indeed opened and enabled a new, unusually fertile era of experimental research of heredity of individual traits ..." (Orel, 1973). This claim that Mendel's studies of hybrids indirectly produced an understanding of heredity also appears in a textbook published in 1914, and in 1922. Correns noted that the laws of heredity were "not formulated by Mendel himself, but were derived from reality only at their rediscovery" (Correns 1922).

After publishing his work, Mendel was urged by botanist Carl von Nägeli to study hawkweed (*Hieracium*). Unbeknownst to Mendel, hawkweeds have an unusual means of reproduction: they are apomictic, meaning that they appear to cross-fertilize

but, in fact, reproduce asexually (their seeds are of maternal origin; see Brannigan 1981, Corcos and Monaghan 1990). Although Mendel could not repeat his *Pisum* results with hawkweed, he reported his results to the Brünn Society for the Study of Natural Science in June of 1869, and published his results the next year. However, unlike with his *Pisum* work, Mendel ordered no reprints and sent no letters describing his work (e.g., see Henig, 2000). Mendel soon lost confidence and abandoned most of his botanical research. Only years later did he resume this research, studying apples and pears. Those studies were solid work, but produced nothing remarkable.[4]

Was Mendel's Work Known to His Peers?

Mendel's paper was sent to more than 100 individuals and libraries (Orel, 1984; Brannigan, 1981). Thereafter, it was cited (as a contribution to hybridization, not heredity) in papers, books, and bibliographic guides throughout the world (including America, England, Middle Europe, Russia, and Sweden) as a contribution to the understanding of hybridization (Olby, 1979; Dorsey, 1944). These citations did not mention that Mendel's work was revolutionary or even out of the ordinary; they were "typical" citations, suggesting that his contemporaries had not misread Mendel's work. Similarly, Mendel's obituaries recognized his work with hybrids (Orel, 1984), but did not indicate that the work was revolutionary. Taken together, these observations indicate that Mendel was not an obscure figure in 1865. Although Mendel's work did not break new ground when it was published, it was known to many of Mendel's contemporaries. In this regard, the alleged "neglect" of Mendel's paper becomes a moot issue, for any "neglect" would be a problem only if Mendel's paper had been considered a pioneering paper by Mendel's contemporaries. It was not; Mendel's paper was merely one of many excellent studies of hybridization.

Mendel had no collaborators to help him and no students to carry on his work; Mendel's only associates lived in the next century (Eiseley, 1959). Mendel did little to promote his work; he did not republish his conclusions, nor did he do a barnstorming tour to promote his work. Mendel, a humble monk, merely announced his results and left the stage.

How Was Mendel's Work Rediscovered?

In early 1900 de Vries, Correns, and Tschermak each published at least one paper in which they noted a 3:1 ratio in the distribution of characteristics in hybrids; these are the papers that comprise the "rediscovery" of Mendel's work. In 1959, Robert Platt (1959) became the first to question the independence of the "rediscovery" of Mendel's paper by de Vries, Correns, and Tschermak:

> "It is usually reported that they all independently rediscovered the Mendelian laws, but as each one quotes the work of Mendel, it seemed to me that it would be interesting to find out ... how far they had gone with their own experiences before being enlightened by Mendel's genius."

If Mendel's paper represented "typical science" when it was published, how was it "rediscovered," and why did it only then become so popular? Although cytology and the germplasm theory in the late 19th-century provided a new context for Mendel's work,[5] its "rediscovery" resulted primarily from a priority dispute among the people who "rediscovered" Mendel's work (e.g., see Locke 1992; Brannigan 1981).

In 1900, Tschermak was a 26-year-old graduate student. His "rediscovery" paper (Tschermak, 1900) was a seven-page summary of his doctoral thesis which noted that Mendel's "premise of regular unequal quantivalency of traits for heredity is fully confirmed in my experiments … and in the observations of Körnicke, Correns, and de Vries in *Zea mays*, and in de Vries' interspecific crosses, and is shown to be of the utmost importance in the science of heredity in general." Tschermak (1900) reported an F_2 ratio of "about 3 to 1" for monohybrids (his results were only slightly closer to a 3:1 ratio than they were to a 2:1 ratio) and a 1:1 ratio in progeny of the backcross. He thus confirmed Mendel's work, but he never generalized principles, nor did he recognize the importance of Mendel's work or the 3:1 ratio. Tschermak did not understand the nature of dominance and recessiveness, nor did he understand the importance of theoretical ratios. Tschermak's understanding of dominance differed from that of Mendel, and his explanation of the concept was inconsistent and contradictory. For example, Tschermak (1900) claimed that in his F_2 offspring,

> "Regularly, one character in question ... comes exclusively into expression (dominating character according to Mendel) in contrast to the recessive character..."

Later in the same paragraph, however, Tschermak contradicts himself:

> "The appearance of the dominating and the recessive character is not a purely exclusive one. In individual cases, I could, on the contrary, detect with certainty a simultaneous appearance of both, that is to say, of transition stages."

This statement contradicts Tschermak's earlier statement as well as Mendel's statement (1866) that,

> "Transitional forms were not observed in any experiment."

Moreover, Tschermak did not discuss why a 3:1 ratio should have appeared, nor did he discuss how segregation could produce a 3:1 ratio. Clearly, Tschermak did not understand that the appearance of transitional forms implies the lack of dominance (also see Monaghan and Corcos, 1987).

Although Tschermak mentioned a ratio of 9:3:3:1 (probably as a result of his reading Correns' paper; see below), his data did not support such an interpretation. This led Stern and Sherwood (1966) to conclude that "Tschermak was "an experimenter whose understanding ... had fallen short of the essential discovery," "Tschermak's designation as a rediscoverer of Mendel has only limited validity," and that Tschermak's "papers not only lack fundamental analysis of his breeding results, but clearly show that he had not developed any interpretation." Others have also rejected the alleged independence of the triple rediscovery (e.g., Olby, 1985).

The priority dispute that elevated Mendel's work was primarily between de Vries and Correns:

- Near the end of the 19th-century, de Vries began studying hybridization and became convinced that traits were inherited as independent units. For example, in 1893 de Vries gathered data showing that crosses of hairy and hairless species of *Lychnis* produced all hairy hybrids, but the following year he described the F_2 generation as consisting of hairy:hairless plants in a ratio of 2:1 (de Vries, 1899). Like Mendel before him, de Vries had been quantifying his results.
- On 26 March 1900, the 52-year-old de Vries presented a paper entitled "On the law of segregation in hybrids" at the *Académie des Sciences*; this paper (which described hybridization in more than 80 species) was published soon thereafter (in French) and was remarkably similar to Mendel's paper (de Vries, 1990a; see translation in Stern and Sherwood, 1966). For example, in his previous papers, de Vries always used the terms *active* and *latent*, but in 1900 he abruptly began using Mendel's terms (*dominant*, *recessive*; see below), yet did not mention Mendel or cite Mendel's work. de Vries, who was studying starchy and sugary fruits of corn, did not mention anything about a law of segregation or a 9:3:3:1 ratio, but elevated Mendel's inconspicuous 3:1 ratio to a law when he reported that "about one-quarter of the grains were sugary; the other three-quarters were starchy."
- Before 1900, de Vries did not think in Mendelian terms, nor had he reported his F_2 results in a 3:1 ratio; he had merely listed or described his F_2 data in a non-Mendelian way. However, de Vries' data for F_2 generations of hybrids changed to 3:1 ratios after 1900. For example, his 2/3 hairy:1/3 nonhairy F_2 ratio for *Lychnis* in 1897 became 3/4:1/4 when they were published in 1900, although the actual data (i.e., 99 hairy vs. 54 nonhairy) were closer to a 2:1 ratio than a 3:1 ratio (Corcos and Monaghan, 1985b).[6] Although de Vries (1900b) gave no explanation for his results, his data could not have led him to the law of segregation (de Vries even claimed that the F_2 data consisted of "the most varied combinations and mixtures"). Similarly, in 1897 de Vries' reported a 80:20 ratio for flower-color in *Linaria vulgaris*; by 1903, de Vries had changed this ratio to 3:1, despite the fact that he had reported that there were three phenotypes ("the great majority were purple, some were white, others dark red ..."; see de Vries 1900d). This suggests that de Vries did not develop his theory of segregation independently of Mendel, although he asserted, from 1900 on, that he had discovered Mendel's laws in 1896 (see Kottler, 1979; Stomps, 1954). As Zirkle (1968) noted, "de Vries either had not read Mendel's paper until a short time before he announced its discovery, or that if he knew of its contents earlier, he had not recognized its importance ... de Vries could have gotten his 3:1 ratio either by reading Mendel or by counting his own plants. His own plants, however, did not give a 3:1 ratio."
- In 1889 de Vries claimed that pangenes could readily change from active to latent forms de Vries 1889). In 1903, de Vries claimed that pangenes were virtually invariant (Theunissen, 1994). Similarly, de Vries' theory of inheritance

became semi-Mendelian only after 1900 (Corcos and Monaghan, 1985b).

- Campbell (1980) has also noted that de Vries' ideas about inheritance changed dramatically in 1900. Before 1900, de Vries repeatedly claimed that all of a species' hereditary traits are borne in germ cells; after 1900, he embraced paired units and claimed that each pollen grain and egg cell received but one of the two traits. Corcos and Monaghan (1985a & b; 1987a-c) and Monaghan and Corcos (1986, 1987) have noted that none of the "rediscoverers ever made a Mendelian interpretation of the data from their hybridizing experiments before 1900." Each tried to do so only after reading Mendel's paper, thus questioning their claims that they had discovered Mendelism independently of Mendel.
- Correns received a copy of de Vries' paper on 21 April 1900. Although Correns' research had a different purpose and was based on different data (i.e., how pollen affects seed color) than Mendel's work, Correns was familiar with Mendel's work; he had published a paper in December, 1899 (Correns, 1899) that mentioned Mendel's research (i.e., that some hybrids have characteristics of their parents). Correns mailed his "rediscovery" paper on 22 April 1900 (i.e., the day after he received de Vries' paper) to *Berichte der deutschen botanischen Gesellschaft*, the most prestigious botany journal in Germany. In that paper, Correns (1900a) inferred that Mendelian segregation and assortment occurred in the nucleus, thereby shifting the focus from theory to mechanism (Gliboff, 1999).
- Although Correns' rediscovery paper was largely an attempt to explain Mendel's paper, it was nevertheless remarkable (Orel, 1996):
    - Correns discovered the 9:3:3:1 ratio for offspring of crosses differing in two traits. Although this suggests that Correns understood the independent assortment of two pairs of genes (with dominance), he never stated such independence.
    - Correns explained Mendel's theory as the determination of each trait by two hereditary units. Bateson later would call these traits allomorphos, then alleles (Bateson, 1894).
    - Unlike de Vries and Tschermak, Correns thoroughly understood Mendel's work (Corcos and Monaghan 1987c). Correns' data (which included tabular results for experiments with *Pisum* and *Zea*) and explanations are more complete and more convincing than are those of either Tschermak, Mendel, or de Vries. Moreover, Correns' discussion went far beyond Mendel's original idea; Correns even suggested a theory of inheritance that is a simple version of what we now call Mendelian genetics. Correns supported his 9:3:3:1 discovery by showing that his data from *Zea* and Mendel's data gave "a good approximation of the ratio."
    - Although Mendel had used the German word *Merkmal* to describe what his rediscoverers later translated as "factor," Correns used *Anlage* – a word that, unlike *Merkmal* and *Elemente*, described a discrete determinant that could move from parent to offspring. In this sense, *Anlage* was much closer to our understanding of a gene than was Mendel's *Merkmal*. *Anlage* also implies that it is not the trait itself, but instead codes for events that lead to the trait (Henig 2000). According to Correns' thinking, each trait had a single *Anlage*, which was either dominant or recessive, whereas hybrids have one of each form. The dominant *Anlage* suppresses the recessive *Anlage*, but doesn't change it.
    - Correns was the first to explicitly link one factor of inheritance with one character; to report cases of linkage; to see that the four different phenotypes produced by a dihybrid cross "must occur in a ratio of 9:3:3:1," and to suggest that segregation was due to meiosis: "The earliest time at which this separation might occur is the time of formation of the primordial *anlage* of both the seed and the anthers. The numerical ratio of 1:1 strongly suggests that the separation occurs during a nuclear division, the reductive division of Weisman..."
    - Moreover, Correns suggested that an organism's entire set of *Anlagen* was in its cells' nuclei (Henig, 2000). These observations question the claim (e.g., Lander and Weinberg, 2000) that Correns' paper "revealed little more than what Mendel had found 35 years earlier."
    - Correns suggested that every trait is based on an *anlage*, which is a hypothetical nuclear unit that causes the trait to be expressed. This explained segregation, dominance, and recessiveness; since hybrids express only one trait, one *anlage* must suppress the expression of another (Corcos and Monaghan, 1990). Correns was the first to suggest that a pair of characters are determined by a pair of *anlagen*, noting that "A complete

separation of the two *anlagen* ... so that one half of the reproductive nuclei receive the *anlage* for the recessive trait, ... the other half the *anlage* for the dominating trait."

- The random recombination of these *anlagen* in zygotes gave Correns an explanation of how the parental types could be recovered from hybrids.

- Of the three rediscoverers, only Correns fully understood Mendel's paper (e.g., Corcos and Monaghan 1990). Correns' conclusion was bold: "*This I call Mendel's Principle ... Everything else may be derived from it*."
- Another paper written by Correns published in 1900 (Correns, 1900b) involving *Levkojen* hybrids defined two Mendelian principles and showed the linkage of some traits. Correns used a footnote to add that Mendel had earlier noted the association of different features (e.g., coloration of seed coat, flowers, and pigmentation of leaf axils).
- Correns claimed to have figured out the explanation of the 3:1 ratio in October 1899, several weeks before he read Mendel's paper, but he did not mention this explanation in the paper that he published in December (Correns 1899). In 1900 (Correns, 1900a), Correns did not cite Mendel's paper, but he did refer to Mendel's earlier discovery: "… the behaviour is the same as that found when yellow and green pea seeds are bastardized, as has been correctly pointed out by Darwin and Mendel."
- When Correns saw de Vries' paper, he suspected that de Vries' wanted to hide Mendel's earlier discovery of the 3:1 segregation ratio. In his "rediscovery" paper, Correns (1900a) used sarcasm and understatement to point out de Vries' use of Mendel's terms (Stern and Sherwood, 1966; emphasis in original): "This one may be called the **dominating**, the other one the **recessive** anlage. Mendel named them in this way, and by a strange coincidence, de Vries now does likewise."
- This was no coincidence, for de Vries had learned of Mendel's paper (that notes a 1:2:1 ratio in F_2 progeny) in 1892 from a bibliography of L.H. Bailey (1892). This may account for de Vries' mention of a "1:2:1 law" for pangenes in hybridization in some of his correspondence before 1900 (Zevenhuizen, 1996). As de Vries later noted in a letter to Bailey (Edwardson, 1962), "Many years ago you had the kindness to send me your article on "Cross-breeding and hybridization" of 1892; and I hope it will interest you to know that it was by means of your bibliography therein that I learnt some years afterwards of the existence of Mendel's papers, which now are becoming to so high credit."
- Just as Correns had de Vries' paper available before he wrote his rediscovery paper, so too did Tschermak have the papers of both de Vries and Correns in hand when he wrote his rediscovery paper. Tschermak (1958) later claimed that when he visited de Vries in Amsterdam in 1898, de Vries knew of Mendel's work and was verifying the results in other hybrids. Such observations have prompted Meijer (1982) to conclude that de Vries – like many others -- knew of Mendel's work before 1900, but "failed to understand its full extent" (also see Corcos and Monaghan, 1987a & b).

- After seeing de Vries' paper (de Vries, 1900a), Correns realized that he'd lost the priority of the discovery of the 3:1 ratio. Rather than allow de Vries to get credit for the discovery, Correns quickly wrote a paper that gave Mendel credit for de Vries' findings (Correns, 1900a). Correns went out of his way to show readers that de Vries' claims were, in fact, made decades earlier by Mendel: "***After my discovery of the law of behaviour and its explanation ... I have experienced what apparently de Vries experiences now: I thought it was something new.*** But then I had to convince myself that the abbot Gregor Mendel in Brünn, during the sixties, had not only come up with the same results as de Vries and I, through his elaborate experiments over many years with peas, but that he had also given the same explanation, as far as that was possible in 1866." (emphasis Correns')

- In the next line, Correns further praised Mendel's work by proclaiming that "Mendel's paper is among the best that have ever been written about hybrids …"
- Correns, who had learned of Mendel's work from his teacher Nägeli (Roberts, 1929), used his paper's title to cite Mendel and elevate Mendel's findings to a "law": "G. Mendel's Law on the Behaviour of Progeny of Variable Hybrids" (Correns, 1990a). Rather than give de Vries credit for Mendel's work, Correns cited Mendel's work as the original idea, and then made himself one of Mendel's prophets (Brannigan, 1981).

These observations are consistent with Mendel's fame being largely due to how Mendel's work was used by others (e.g., Correns and de Vries) to promote themselves in a priority dispute. Indeed, Correns ensured that Mendel, not de Vries, would get credit for the 3:1 ratio, and thereby played a major role in transforming Mendel's results into Mendel's laws. Correns' paper read importance back into Mendel's original work, and was a critical step in the "rediscovery" of Mendel (MacRoberts, 1985).

Unbeknownst to Correns, de Vries had written another paper -- one of three that he wrote in 12 days (de Vries, 1900b; also see Zirkle, 1968; Roberts, 1929). This was the only one of de Vries' "rediscovery papers" in which de Vries discussed the results of his dihybrid crosses. In that paper (written in German and submitted for publication on 14 March 1900), de Vries promoted his theory of pangenesis. He also mentioned Mendel:

> "From these and other numerous experiments I conclude that the law of segregation of hybrids as discovered by Mendel for peas has a very general application in the plant kingdom, and has a basic significance for the study of the units of which the specific characters are composed."

Contrary to this claim by de Vries, Mendel never stated a law of segregation; de Vries must have inferred it from Mendel's paper (consistent with this is the fact that de Vries stated it differently in each of his "rediscovery" papers). de Vries noted that recessive traits in his crosses accounted for 22-28% of hybrids' progeny, and that back-crosses yielded a segregation ratio of 1:1 (de Vries 1990b). de Vries used a footnote to add that Mendel's work "is so rarely quoted that I myself did not become acquainted with it until I had concluded most of my experiments, and had independently deduced the above propositions." Neither Mendel nor de Vries ever mentioned that there is one unit of heredity in sex cells or that there are two in vegetative cells.

de Vries' appreciation of Mendel's ideas was short-lived, however. After initially believing that Mendel's work supported his theory of pangenesis, de Vries subordinated Mendel's theory to his own theory of mutation, despite the fact that his explanations entangled him in many contradictions (e.g., Stamhuis, et al., 1999). de Vries claimed that Mendel's data were for a "special case" (Meijer, 1982; MacRoberts, 1985; Olby, 1985),

> "The essential parts of these principles ... have been formulated already by Mendel a long time ago for a special case (peas). They went into oblivion ... and were overlooked."

In a third paper, also published in 1900, de Vries (1900c) summarized how his experiments with hybrids related to his theory of intracellular pangenesis. de Vries concluded that,

> "This law is not new. It was stated more than thirty years ago, for a particular case (the garden pea). Gregor Mendel formulated it in a memoir entitled "Versuche über Planzaenhybriden" in the Proceedings of the Brünner Society. Mendel here has shown the results not only for monohybrids, but also for dihybrids."[8]

William Bateson, a Cambridge zoologist who rejected Darwin's ideas about gradualism, learned of Mendel's work by reading de Vries' and Correns' "rediscovery" papers. On 8 May 1900, while aboard a Great Eastern Railway train to the meeting of the Royal Horticultural Society in Liverpool, the 40-year-old Bateson read Mendel's paper and recognized its significance (Bateson's wife remarked that it was as though "with a very long line to hoe, one suddenly finds a great part of it already done by someone else." Bateson rewrote his lecture to feature Mendel's work. Bateson, who later extended the validity of Mendel's theory to the animal kingdom (Bateson and Saunders, 1902), believed that Mendel's work confirmed his concept of discontinuous variation (Bateson, 1894). Soon after reading Mendel's paper, Bateson used Mendel's work to proclaim the birth of a new science – he termed it ***genetics*** -- that was in total opposition to Darwin's ideas. Bateson also noted that some of the key findings in the papers by de Vries and Correns were made by Mendel (MacRoberts, 1985; Olby, 1985). Bateson and several others had Mendel's paper re-published in several English-language journals and books (Brannigan, 1979 & 1981), thereby completing the promotion and accompanying "rediscovery" of Mendel's work.

Perhaps de Vries did not consider the Mendelian discovery to be important as he pursued his own research (Stamhuis, 1995). Nevertheless, de Vries continued to downplay Mendel's contributions

(Theunissen, 1994; Stamhuis et al, 1999 and references therein). In late 1901, de Vries continued his efforts to convince Bateson that Mendelism "is an exception to the general role of crossing" and claimed that the separation of hereditary factors does not occur in Mendelian crosses (Stamhuis et al., 1999). Later, de Vries refused to sign a petition calling for the construction of a memorial to Mendel in Brünn, and even rejected an invitation to attend a 1922 celebration of Mendel's work. As he explained to his friend F.A.F.C. Went in September of that year (Stamhuis et al., 1999),

> "To my regret I cannot accede to your request. I just don't understand why the academy would be so interested in the Mendel celebrations. The honoring of Mendel is a matter of fashion which everyone, also those without much understanding, can share; this fashion is bound to disappear. The celebration in Brünn is nationalistic and anti-English, directed especially against Darwin and thus unsympathetic to my mind but, therefore, also very popular."

Summary

The history of science includes many famous priority disputes (e.g., Leibniz and Newton about calculus; discovery of the AIDS virus; see Hellman, 1998). Similarly, many important findings have been known but ignored for decades (e.g., Barbara McClintock's discovery of transposons). Many aspects of the "rediscovery story" of Mendel's paper are inaccurate. Mendel's original paper announced no major findings; it was known and acknowledged as "typical" science for its day. When it was "rediscovered," Mendel's paper became famous as a result of a priority dispute between de Vries and Correns. This dispute prompted researchers to reinterpret and read importance into Mendel's paper.

Footnotes

1. Since 1918, Brünn has been known by its Czech name Brno.
2. To deduce "true numerical ratios," Mendel knew that large sample-sizes were essential; as he explained, "the greater the number, the more effectively will mere chance be eliminated." Mendel, who hand-pollinated his plants, was also keenly aware of the tedium that these large samples produced; as he noted, "It requires indeed some courage to undertake a labor of such far-reaching extent; this appears, however, to be the only right way by which we can finally reach the solution of a question the importance of which cannot be overestimated in connection with the history of the development of organic forms" (see Simmons, 1996). The methods that Mendel used to design his experiments and interpret his results were influenced by his studies of math and physics when he attended the University of Vienna. Until 1854, Mendel had studied breeding mice. However, the church didn't like this work, and Mendel was encouraged to change his research. Thus, when Bishop

Anton Ernst Schaffgotsch visited Mendel in Brünn in 1854, Mendel agreed to begin growing plants. He later noted, "the bishop didn't understand that plants also have sex" (Henig, 2000).

3. Although Mendel may have had other important insights, we'll never know; his experimental notebooks were destroyed after he died.
4. Contrary to myth, Mendel was not a shy, secluded person; he traveled, was active in several professional societies, directed an organization for deaf and mute children, and was chairman of mortgage bank (Iltis, 1932). In addition to working in the monastery's garden and 550-year-old glasshouse, Mendel devoted much of his time to bee-keeping and meteorology; for almost 30 years, Mendel collected weather data three times per day, and during his lifetime, Mendel was more famous for forecasting the weather than for breeding plants (Orel, 1996). Mendel also spent a lot of time doing the administrative chores that accompanied his appointment on 30 March 1868 as abbot of the modest St. Thomas monastery. Near the end of his life, Mendel's administrative duties embroiled him in a bitter tax-dispute with the government, and he isolated himself from most people. He then developed heart disease and kidney problems, and began smoking 20 cigars per day. He spent his last days sitting on a couch with his feet in bandages (Simmons, 1996). For more about Mendel's life, see Orel (1996) and http://www.stg.brown.edu/MendelWeb/
5. For example, new ideas from cytology led de Vries to his theory of intracellular pangenesis. de Vries rejected much of Darwin's "gemmules" hypothesis, and renamed the carriers of heredity *pangenes* (de Vries, 1889).
6. Before 1900, de Vries reported his data as raw data, not ratios. This is consistent with de Vries not having had a Mendelian perspective before 1900. Indeed, there is a big difference between reporting numbers of plants having different characteristics, discerning a similar ratio, and deducing a theoretical ratio that leads to a fundamental understanding of biology.
7. Before 1900, de Vries did not claim (as he did in 1900) that *anlagen* are side-by-side in hybrids and separate in egg and pollen. Instead, de Vries used a model of an urn with black and white balls, from which came two balls represented the formation of offspring.
8. In fact, Mendel (1866) performed seven monohybrid studies, two dihybrid studies, and one trihybrid study.
9. Bateson later rejected and campaigned against the chromosomal theory of heredity (Olby, 1985). Bateson's vigorous promotion of Mendelism (and his rejection of Darwinian evolution) hindered the development of genetics in Great Britain (Olby, 1985). At the end of his life, Bateson admitted to his son Gregory (named after Mendel) that his devotion to Mendelism "was a mistake," for it was "a blind alley which would not throw any light on the differentiation of species, nor on evolution in general" (Koestler, 1971)

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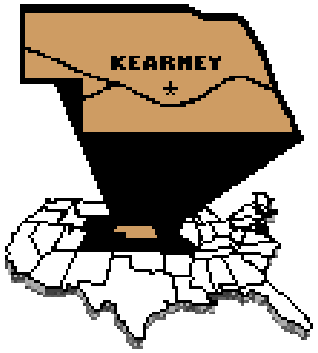
ACUBE

45th Annual Meeting

University of Nebraska at Kearny
Kearney, NE

October 11-13, 2001



Biology in the Light of Evolution

Call for Nominations

President-Elect, Secretary & Steering Committee Members

ACUBE members are requested to nominate individuals for the office of President-Elect, Secretary and two at large positions on the ACUBE Steering Committee.

If you wish to nominate a member of ACUBE for a position, send a Letter of Nomination to the chair of the Nominations Committee: Dr. Lynn Gillie, Dept. of Biology, Elmira College, One Park Place, Elmira NY 14901, Voice -- (607) 735-1859, E-mail --lgillie@elmira.edu

University of Nebraska at Kearney
Department of Biology
Kearney, Nebraska

Site of the 45th Annual ACUBE Fall Meeting

October 11-13, 2001

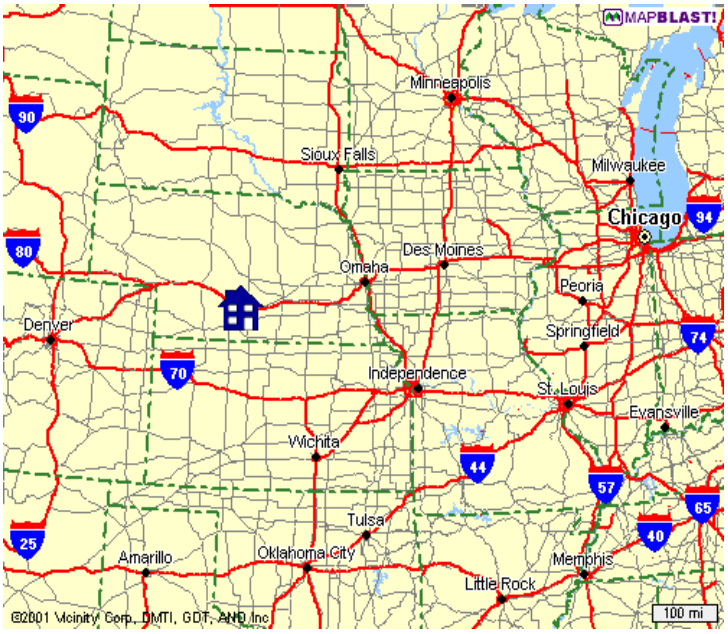
History: The University of Nebraska at Kearney began as the Nebraska State Normal School in 1905. In 1921, the name of the institution was changed to Nebraska State Teacher's College at Kearney. In 1963, it became Kearney State College. Both names were a part of system-wide changes for the state. In 1989, however, legislative action moved the institution from the State College System to the University of Nebraska System. The university community is in its 10th year as a NU System campus.

Mission: Today, UNK is a comprehensive residential university distinguished by its commitment to be the state's premier institution for undergraduate education. The university pursues the preservation, enrichment, and transmission of knowledge and culture across a broad scope of academic disciplines. It places the highest priority on programs of instruction and learning that educate students to be lifelong, independent learners. UNK has 350 faculty, 7000 students, and about 30,000 living alumni. UNK has 176 undergraduate programs, and offers masters degrees in several disciplines.

Department of Biology: The Department of Biology has 15 tenure track faculty, 3 full time lecturers, and about 250 majors. The Department also offers the thesis-focused M.Sc. degree as well as an M.Sc. science teaching (MSST) degree. The Department stresses both the content and processes of biology in seven emphasis areas; the comprehensive major, agricultural emphasis, environmental emphasis, environmental health emphasis, molecular emphasis, wildlife emphasis, and secondary biology education. All students complete an extended independent research project that culminates with a scientific research report written in the conventional fashion, a 20 minute oral presentation in the format of a scientific meeting, and submission of a poster. Student posters adorn the halls of the Biology floors celebrating the accomplishments of recent graduates.

The faculty typically teach "across the curriculum" with most involved in both majors and general education biology courses as well as lower and upper division offerings. Active faculty "groups" in prairie ecology and molecular biology have formed in recent years. This dynamic clustering of 3-5 faculty in each instance has enhanced undergraduate research opportunities.

Geography: The city of Kearney lies just north of the Platte River; the key water resource for wildlife and agricultural production across central Nebraska. Renown for the annual spring migration of some 500,000 sandhill cranes, the central "Big Bend" region of the Platte River harbors other migratory waterfowl in the spring, bald eagles in the winter, and an abundance of other wildlife. The Department of Biology utilizes or manages classic tallgrass prairie preserves in the lowland areas along the river and mixed grass prairie preserves in the upland loess hills minutes north of Kearney.



Kearney, a city of 30,000, is home to the Museum of Nebraska Art (MONA), the Great Platte River Road Archway Monument, a Cabela's sporting goods outlet, and Fort Kearny State Historical Park. The Fort adjacent to the Platte River along the Oregon, Mormon, and California Trails was a major staging ground for pioneers heading west.

Travel and Housing Preview

45th Annual ACUBE Fall Meeting
University of Nebraska at Kearney
October 11-13, 2001

Travel by Air

- Kearney has four arrivals and departures daily via United Express. All flights connect with Denver International Airport, the hub for United Airlines.
- Lincoln is just under 2 hours to the east of Kearney and is served by TWA, Northwest, United, and US Air Airlines. Omaha is just under 3 hours to the east with non-stop service several times a day from St. Louis (TWA), Chicago (United – O'Hare and Southwest – Midway), Minneapolis (Northwest), Milwaukee (Midwest Express), and Indianapolis (United).
- Eppley Express, a shuttle service, has three daily departures and arrivals from both the Omaha and Lincoln airports to Kearney. The fare is $34 one way from Lincoln and $42 from Omaha. The drop point in Kearney is the Country Inn Suites.

Travel by Car

- Kearney is 5 hours by car from Kansas City, 5 hours from Denver, 7 hours from Minneapolis, and 10 hours from Chicago.

Lodging

Kearney has 20 motels; several of which are on the Second Avenue corridor just off Interstate 80 and about one mile south and one mile east of the University of Nebraska at Kearney campus. Among those motels with tentative arrangements expressly for ACUBE meeting participants are:

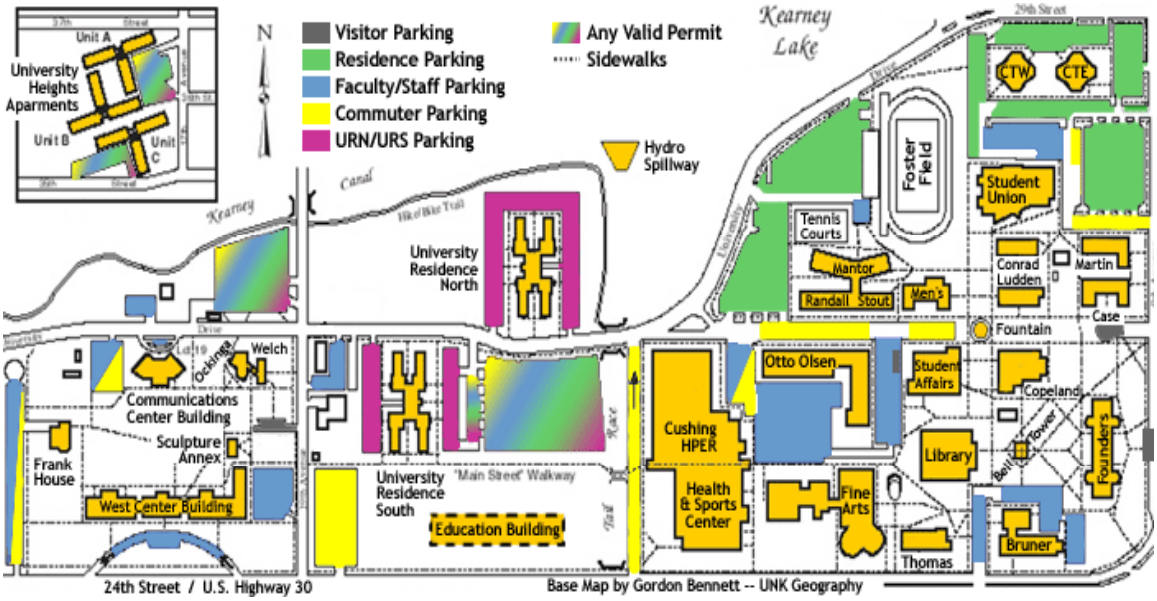
Holiday Inn
110 2nd Ave.
P. O. Box 1925
Kearney, NE 68847
308-237-5971 or 800-248-4460

Hampton Inn
118 3rd Ave.
Kearney, NE 68847
308-234-3400 or 800-426-7866

Wingate Inn
108 3rd Ave.
Kearney, NE 68847
308-237-4400 or 800-800-8000

Country Inn & Suites *
105 Talmadge St.
Kearney, NE 68847
308-236-7500 or 800-456-4000

* Location of the Eppley Express shuttle drop.



From Yeast to Hair Dryers: Effective Activities for Teaching Environmental Sciences

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Abstract: Four experiments and/or activities were used to stimulate student interest in the arena of environmental science. Yeast was grown within a class period to demonstrate population growth. Soil samples, collected beforehand by students, were tested for nutrients and pH. The overflow of non-essential luxuries and non-recyclable packaging materials in our society was demonstrated through the "needs" and "wants" bag activity. Art was incorporated into the curriculum through a visit to a photography exhibit that depicted the recycling of ships. Varying classroom activities in the environmental science classroom made the teaching and learning experience feel more alive and vital to both the instructor and the student.

Key Words: environmental science, yeast, soil testing, pH, nutrient, recycling

Introduction

The following activities were successfully employed in my Ecology and the Environment course for non-science majors at St. Francis College. These exercises could be tailored to courses with similar goals, or serve as a springboard for further ideas for activities.

1. The use of yeast as an organism to introduce population growth.

Materials per student group:

- 1 125 ml Erlenmeyer flask (250 ml flasks work as well; however, the experiment takes a little longer)
- 1 pkg. baker's yeast
- 2 sugar packets
- 1 piece of newspaper
- large beaker or flask of warm water 40-45^{o} C, dispense 50 ml into each flask
- hot plate (optional) if you would like to have the warm water ready ahead of time

I needed something to demonstrate population growth and how it could be quite rapid. The majority of the non-science majors, that I have taught, have been resistant to terms such as "exponential growth" so I needed a system that would visually demonstrate a relatively rapid growth within a class period that I would not need to quantify. (Bacterial growth doesn't occur rapidly enough to demonstrate significant changes during the class period, although inoculations can be done of bacterial cultures in front of the class, left overnight to incubate, and the "cloudiness" as evidence of bacterial growth can be shown to the students the next day.)

Yeast reproducing inside a flask and the subsequent production of carbon dioxide gas make a good demonstration of population growth and decline that can be demonstrated within the class period. This system can also lead to a discussion of global warming because of the carbon dioxide production.

The set-up for this experiment can be accomplished in the ten minutes that are usually available between classes, and it lends itself well to lecture classes of 30 or so. With larger classes, it could be conducted effectively with the help of student assistants. The limiting factor in this experiment is the temperature of the water, which should be quite warm, (40-45^{o}C) but not scalding to the touch -- the yeast will not reproduce as quickly in cooler water. Between classes, I put a piece of newspaper down at each work site (students work in pairs) and place the flask, a package of Bakers yeast, and two sugar packets at each place. Just before class begins, I literally jog to the

nearest bathroom to obtain hot water, fill the flask with steaming water, and pour 50 ml into each of the student's (and one control) flask. I instruct the students to add a package of yeast and two sugar packets to their flasks and swirl the contents. I point out to them that I am adding the yeast only to my flask. (Another activity that could be included is to have students make microscope slides of yeast.)

I then ask the students a series of questions to which they may or may not know the answers. I write the questions on the board and ask them to discuss them with their partners before volunteering answers.

1. What do they think will happen in their flasks? *(The yeast will grow.)*

2. What is the evidence of this growth? *(The gas production. It could be used also to demonstrate, in a separate experiment, that the correct temperature is necessary for yeast to grow, at a suitable rate..)*

3. What do they think will happen in my flask? *(Nothing.)*

4. Why? *(Because there is no sugar available -- -it is a limiting factor in this case.)*

5. What are other limiting factors in this situation? *(Temperature, space, waste production.)*

6. What will happen over time to your experiment? *(It will experience a population crash.)*

7. What is the name for my flask and why is it used? *(A control. It is used to demonstrate, in this case, that yeast require sugar to grow.)*

These questions may lead you to think of other questions such as:

How have human utilized yeast in the past and/or present?

What would happen if you added another species of bacteria or yeast to the flask?

How has an increased production of carbon dioxide over time changed the world?

By the time the class has answered a few questions, the yeast should be producing carbon dioxide at a rate that can be seen by the students, and often the flask will bubble over, hence, the newspaper (Figure 1). At the end of the class, I save a few flasks so I can show the students the "population crashes" that have occurred over time.

Figure 1. Yeast population growth experiment.

The whole exercise takes around a half-hour. It is popular with the students as it is very visual, and it is a good lead-in to a lecture or discussion of population growth and/or population dynamics.

2. Soil testing

I always thought that learning about soil would be too boring for this class. However, Ruth Beattie of the University of Kentucky demonstrated otherwise. I attended a workshop that she conducted in June, 2000 at Clemson University titled, " Bringing the laboratory into the lecture hall" (Beattie, 2001). She gave us zip-lock bags with spoons, soil test kits, and film canisters and had us test soil for the presence of various nutrients. I bought some Rapitest ^{TM} soil test kits from a local nursery and repeated a similar version of the exercise with my students. The kits come with some mixing containers, but you will need to provide beakers, water (tap is fine), test tubes, spoons, and droppers. The students were asked to bring in soil samples and some of each sample was mixed with water in a beaker. We allowed 10 minutes for the soil to settle (the tests work better if you wait longer) and tested some of the liquid for nitrogen, potassium, phosphorus, and pH. The kits come with pre-measured chemicals in capsules, so they are very easy to use. A chart was drawn on the board with the headings: name of student, N, K, P and pH. The students filled in the different qualitative values (low, medium or high) for each nutrient, and the pH was recorded. The values were estimated by comparing the color of the soil/water mixture against the various colored charts available. The kit comes with a chart that suggests which type of plants can grow in which type of soil, so the students were asked to plan a sample garden utilizing their soil. As Ruth says, the students tend to become possessive of and quite interested in their soil!

3. "Needs" and "wants" bag

I got the idea for this exercise from the Instructor's Resource Manual (Ostiguy, 2000) with the Nebel and Wright textbook "Environmental Science:

the Way the World Works"(Nebel and Wright, 2000). (This manual is provided to the instructor upon text adoption.) This activity always gets a few laughs from the students. I fill a large plastic shopping bag with "junk" from my apartment or office -- souvenirs, small trophies, cheap jewelry, air refreshener spray, deodorant, gum, meat tenderizer, a Frisbee, CD, paper bag, paper cup, Styrofoam meat packing tray, toys, newspaper, flyers, aspirin, comb, make-up, lotion, paper, ribbon, and, of course, a hair dryer. I have the students take turns holding up the various items, and I ask, "Is this item a "need" or a "want"? Most students correctly reply that each item is a "want", although a few still insist that deodorant is a "need"!. We then make a list of "needs" and "wants" on the board. We also have a list of "secondary needs", and on that list we put many of the "want" items because they are needed as a result of our culture -- newspapers and combs are commonly cited examples. Individual items in the bag can also lead to further discussion, such as: air refresheners are actually a component of indoor air pollution, many of our foods have excess packaging that is non-biodegradable and Styrofoam and plastic wrap are non-recyclable. Hair dryers and other items such as computers and CD players require energy to run them resulting in pollution (burning fossil fuels). The whole point of this exercise is to show the students how much people in developed countries consume, waste, and pollute in their everyday use of commercial goods. People in developing countries make less money than we do, and consequently buy fewer of the non-biodegradable or non-recyclable goods.

4. Integrating art into the curriculum.

Last semester, St. Francis College displayed a temporary art exhibit of photographs "Shipbreaking" by Robert Bailey in the college art gallery. This exhibit happened to coincide with the publication of an article "The Shipbreakers" by William Langewiesche in the August, 2000 issue of the Atlantic Monthly (Langewiesche, 2000). Both the article and the exhibit contained photographs of people from India and Bangladesh doing the dirty, backbreaking work of shipbreaking, which is the recycling of ships. The students visited the exhibit during class time and were directed to write a paragraph describing what they saw in one photograph (there were twenty or so in the exhibit), and how it made them feel about the connection of the photographic subject to the environment.

I typed each of the paragraphs with a different font and made a booklet of the students' writings. This was presented to the photographer whom I invited to come to the college to give a talk about his exhibit. Mr. Bailey became interested in Bangladesh, when, as a young boy, he read about the intensive flooding that killed 100,000 people. He wondered how this could actually have occurred and he vowed to visit Bangladesh one day. He lived in Bangladesh for a month while photographing, and was able to tell some poignant stories about these peoples' lives. (Ironically, Bangladesh has recently been in the news again with accounts of flooding that killed thousands.) The students, in this way, were exposed to two points of view; that of the author of the Atlantic Monthly article who felt the people were being gravely exploited by those in the developed countries (from my notes), and that of Robert Bailey, who felt that these people experienced a dignity in their work, even though they suffered hardships.

Other material that I have used for my classes has been derived from museum exhibits--notably the solar energy exhibition titled "Under the Sun: An Outdoor Exhibition of Light" at the Cooper Hewitt National Design Museum (1998), and the permanent Hall of Biodiversity exhibit at the American Museum of Natural History. Past assignments for this course have also included a self-paced trip to the Brooklyn Botanic Garden.

Conclusions

I find that my teaching gets a little stale if I don't have these " classroom props"--- as one of my students has coined them---which include easy experiments or activities in which students can participate, visits to museums and galleries, and outside speakers. It adds a little color and refreshment to these classes that we teach semester after semester by introducing a new activity, face and/or point of view -- and the students appreciate it.

Literature Cited

Beattie, R. 2001. Bringing the laboratory into the lecture hall. *In*: Proceedings of the 22nd Conference of the Association of Biology Laboratory Educators (ABLE) (*in press)*. ABLE website: http:/www.zoo.utoronto.ca/able.

Langewiesche, W. 2000. The shipbreakers. Atlantic Monthly 28 (2): 31-49. (available on line at: http:/www.theatlantic.com (search for: shipbreaking).

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Ostiguy, N. 2000. Instructor's resource manual for: Environmental Science: The Way the World Works. Prentice Hall.

Rapitest™ soil test kit is available through http:/www.gardendepot.com. Search for soil test kits. Price: $15.95.

Call For Resolutions

The Steering Committee of ACUBE requests that the membership submit resolutions for consideration at the 2001 Annual meeting to the Chair of the Resolutions Committee. Submit proposed resolutions to:

Dr. Richard Wilson
Dept. of Biology
Rockhurst University
1100 Rockhurst Rd
Kansas City, MO 64110
Phone (846) 501-4048
wilson@vax1.rockhurst.edu

ACUBE 45TH Annual Meeting

October 11-13, 2001

University of Nebraska at Kearney
Kearney, NE

Biology in the Light of Evolution

Preliminary Program

Thursday, October 11th

6:00 - 8:00 PM	**Registration and Reception**	Bruner Hall Lobby (Science Building)
8:00 - 9:00 PM	**Opening Session** **Welcome to ACUBE**: ACUBE President: *Tom Davis, Loras College, IA* **Welcome to University of Nebraska at Kearney:** Dean *College of Arts and Sciences* Program Chair: Mary Haskins*, Rockhurst University* Local Arrangements Chair: Charles Bicak, University of Nebraska at Kearney **OPENING ADDRESS** (Public Welcome to Attend) ***Biology of Sandhill Cranes*** Presenter: Paul Tebbel, Manager of the Audubon Sanctuary, Kearney, Nebraska	Mary Morris Lecture Hall (in Bruner Hall)
9:15 - 10:15 PM	**Executive Committee Meeting**	Bruner Hall Reading Room (3rd floor)

Friday, October 12th

7:00 AM - 5:00 PM	**Registration table will be open all day** Please check your membership; Inquire about audiovisual needs. General information.	Bruner Hall Lobby (Science Building)
7:00 - 8:00 AM	**Buffet Breakfast** (by Interest Group)	Cedar Room (Nebraskan Student Union)
7:30 - 10:30 AM	**Field Trip**: Platte River & Audubon Rowe Sanctuary	TBA
9:00 AM - Noon	**SUSTAINING MEMBER EXHIBITS** (refreshments provided)	Bruner Hall (2nd Floor Lounge)

8:15 - 9:45 AM	**CONCURRENT WORKSHOP SESSIONS I**	
9:50 - 10:20 AM	**POSTER SESSION I** (Refreshments available Bruner Hall, 2nd floor lounge)	Bruner Hall (3rd floor hallway)
10:30 AM - noon	**CONCURRENT WORKSHOP SESSIONS II**	
10:30 - 11:15 AM	**CONCURRENT PAPER SESSIONS I**	
11:20 - 12:05 AM	**CONCURRENT PAPER SESSIONS II**	
12:15 - 1:00 PM	**Luncheon and First Business Meeting** *First and Final Call for Nominations!!*	Cedar Room (Nebraskan Student Union)
1:00 - 1:45 PM	**Luncheon Program** ***"Brains Versus Bugs: Evolution's Role in Humanity's War Against Insects"*** Leon Higley, University of Nebraska-Lincoln	
2:00 - 5:00 PM	**SUSTAINING MEMBER EXHIBITS** (refreshments provided)	Bruner Hall (2nd Floor Lounge)
2:50 - 3:20 PM	**POSTER SESSION II** (Refreshments available Bruner Hall, 2nd floor lounge)	Bruner Hall (3rd floor hallway)
3:30 - 5:00 PM	**CONCURRENT WORKSHOP SESSIONS III**	
5:05 - 5:45 PM	**Web Page Committee Meeting**	Bruner Hall Reading Room (3rd floor)
6:00 - 7:00 PM	**Social** (resumes of candidates available for review)	Alumni House (located south of Bruner Hall)
7:00 - 9:00 PM	**BANQUET and Second Business Meeting** (two-minute speeches prior to banquet; balloting after dinner presentation) **Dinner Presentation** : ***"The Evolution of HIV"*** Marcia Kalish, PhD., Centers for Disease Control and Prevention	Cedar Room (Nebraskan Student Union)

Saturday, October 13th

7:30 - 8:45 AM	**Buffet Breakfast** (by Interest Group)	Cedar Room (Nebraskan Student Union)
7:45 - 8:45 AM	**Bioscene Editorial Board** *Ethel Stanley and Tim Mulkey, Co-Editors, presiding*	Oak Room (Nebraskan Student Union
9:00 - 9:45 AM	**CONCURRENT PAPER SESSION IV**	
9:45 - 10:00 AM	**Morning Break**	Bruner Hall Lounge (2nd floor)

10:00 - 10:45 AM	**CONCURRENT PAPER SESSIONS V**	
11:00 AM - 12:15 PM	**Luncheon and Third Business Meeting** **BUSINESS MEETING** Election Results: *Lynn Gilley, Elmira College* Resolutions: *Dick Wilson, Rockhurst University* Executive Secretary Report: *Pres Martin, Hamline University* Bioscene: *Ethel Stanley, Beloit College & .Tim Mulkey, Indiana State University* Presidential Address: *Tom Davis, Loras College and Malcolm Levin, SIU-Springfield* 2002 Meeting: *Columbia College, Chicago* ADJOURNMENT OF REGULAR MEETING Join us on Sunday for your choice of several optional field trips: (hiking in a prairie, visiting several museums, or shopping at Cabela's)	Cedar Room (Nebraskan Student Union)
12:30 - 1:15 PM	**Steering Committee Meeting** Includes newly elected Steering Committee members!	Oak Room (Nebraskan Student Union)

Submit Your Abstract Today !!! Mail your completed abstract form, found in this issue, to: Mary Haskins, Biology Department, Rockhurst University, 1100 Rockhurst Road, Kansas City, MO 64110. Abstracts must also be submitted either on-line or via an e-mail attachment: on-line at http://acube.org/2001_meeting.html; e-mail: mary.haskins@rockhurst.edu. Deadline for papers and workshops is July 1, 2001. Deadline for posters is September 1, 2001. For additional information contact Mary Haskins @ 816-501-4006.

ACUBE Gratefully acknowledges the support of the following sponsors and exhibitors of the 44th Annual meeting:

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Manuscript Guidelines for
Bioscene: Journal of College Science Teaching

A publication of the Association of College and University Biology Educators

Manuscripts submitted to the Bioscene should primarily focus on the teaching of undergraduate biology or the activities of the ACUBE organization. Short articles (500-1000 words) such as introducing educational resources provided by another organization, reviews of new evolution software, suggestions for improving sampling methods in a field activity, and other topics are welcome as well as longer articles (1000-5000 words) providing more in depth description, analyses, and conclusions for topics such as introducing case-based learning in large lectures, integrating history and philosophy of science perspectives into courses or initiating student problem solving in bioinformatics.

Please submit all manuscripts to editor(s):

Ethel Stanley
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stanleye@beloit.edu
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Indiana State University
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We prefer receiving manuscripts as Rich Text Format or RTF files to facilitate distribution of your manuscript to reviewers and to work on revisions. You can mail us a disk or attach your file to an email message with the subject line as **BIOSCENE**. All submissions should be double-spaced and may follow the style manual for publication you are currently using such as APA. You will also need to include:

- title
- author(s) information:
  - full names
  - name of your institution with the address
  - email address, phone number, and/or fax number
- brief abstract (200 words or less)
- keywords
- references in an appropriate format

Please refer to issues of the Bioscene from 1998 or later for examples of these items. You can access these issues at: **http://acube.org/bioscene.html**

Graphics are desirable! Lengthy sections of text unaccompanied by tables, graphs or images may be modified during layout of the issue by adding ACUBE announcements or other graphics. While tables and graphs may be included in the manuscript file, images should be submitted as individual electronic files. If you are unable to provide an image in an electronic format such as TIFF for Macintosh or BMP for Windows, please include a clear, sharp paper copy for our use. At this time, graphics will be printed as grayscale images with a minimum resolution of 300 dpi and a maximum resolution of 1200 dpi. Cover art relating to an article is actively solicited from manuscript contributors.

Upon receipt of your manuscript, an email or fax will be sent to the author(s). The editor will forward your manuscript to the chair of the editorial board. Within the next two weeks or so, your manuscript will be sent to two reviewers. You should receive comments when changes are recommended from the reviewers prior to publication of the article. Manuscript format is usually retained as accepted; however, limits of publishing the issue may affect the length of an article. Graphics may be added by the editors when lengthy sections of text are unaccompanied by tables, graphs or images. Previously published work should be identified as such and will be reviewed on a case-by-case basis. Your article will appear in the Bioscene and then on the ACUBE website: **http://www.acube.org** shortly after the issue date.

Call for Presentations

Association of College and University Biology Educators (ACUBE)

45th Annual Meeting
University of Nebraska at Kearney
Thursday October 11- Saturday October 13, 2001

Biology in the Light of Evolution

Theodosius Dobzhansky stated, “nothing makes sense except in the light of evolution”.

Evolution has, once again, claimed national attention because some states have either removed and/or downplayed evolution from the curriculum objectives in the K-12 system. Although the scientific community understands the distinction between science and religion, the public may not. The upcoming PBS television broadcast on evolution will continue to promote public discussion and controversy. How can we address our students’ need, and the public’s need, to understand this distinction?

Presentations, posters and workshops addressing other topics are welcome, but here are some examples of possible presentations:
Issues in teaching evolution to non-majors/majors (creationism vs. evolution; Simulation software used in lecture and/or labs; Investigative labs; Evolution of ideas and/or theories in scientific disciplines; Evolution of Scientific methodologies; Evolution of processes, human practices and/or cultures; Analogies used in teaching evolution

Many of you have addressed these issues in creative ways. Please consider sharing your ideas and techniques at the ACUBE 45th Annual Meeting in Kearny, NE in 2001.

Please email your abstract **AND** mail or FAX a hard copy of the abstract with the completed form BEFORE **July 1, 2001** (abstracts received after July 1,2001 will be considered as the program permits) to:

Mary Haskins, Biology Department, 1100 Rockhurst Road,
Rockhurst University, Kansas City, MO 64110
Phone (816)501-4006 FAX: (816)501-4802 email: mary.Haskins@rockhurst.edu

Proposed Title:_____
Presentation type: Poster 45 minute paper 90 minute workshop
Name of presenter : _____
Work address of presenter : _____
_____

Equipment/facilities needed:
____ 35 mm slide projector ____Overhead projector
____ Macintosh projection system ____ Macintosh computer lab
____ PC projection system ____ PC computer lab
____ Other: (explain)

Phone No. presenter: _____ email _____
Please include names and contact information for additional presenters and a 200 word abstract:

ACUBE

Association of College and University Biology Educators

NAME: _____ DATE: _____

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MAJOR INTERESTS

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( ) 2. Botany
( ) 3. Zoology
( ) 4. Microbiology
( ) 5. Pre-professional
( ) 6. Teacher Education
( ) 7. Other _____

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( ) A. Ecology
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How did you find out about ACUBE? _____

Have you been a member before: _____ If so, when? _____

DUES (Jan-Dec 2001) Regular Membership $30 Student Membership $15 Retired Membership $5

Return to: Association of College and University Biology Educators, Attn: Pres Martin, Executive Secretary, Department of Biology, Hamline University, 1536 Hewitt Avenue, Saint Paul, MN 55104