Developing Analytical and Communication Skills in a Mock-Trial Course Based on the Famous Woburn, Massachusetts Case

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ABSTRACT

A mock trial in which undergraduates serve as expert witnesses and law students serve as their attorneys is an effective vehicle for developing quantitative skills and enhancing written and oral communication skills. I have developed an interdisciplinary course based on the book *A Civil Action*. The book deals with the legal struggle of families in Woburn, Massachusetts, who sued two corporations alleging that improperly handled industrial chemicals entered the groundwater system, were captured by two municipal wells, and prolonged ingestion of the contaminated water caused leukemias and other health disorders. Students analyze aerial photographs, well logs, streamflow records, permeability tests, and water-level and water-quality data from the trial to complete assignments that become exhibits in the mock trial. Assignments include construction of geologic cross sections, potentiometric maps, hydrographs, flood recurrence graphs, and calculation of hydraulic gradients, groundwater velocities, and contaminant travel times. Trial transcripts and newspaper articles serve as background materials for a term paper. Based on the computational assignments, background readings, and a discussion of professional ethics, students compose an expert opinion from the viewpoint of their client and are deposed by opposing counsel. A jury of undergraduates is impaneled for the one-day mock trial in which the law students make opening statements and closing arguments, and conduct direct examinations and cross examinations of the scientific experts. The course teaches students how to develop and defend their opinions, how to question the opinions of others, the limitations of data collection and analysis, and the importance of integrating computational and communication skills.

Keywords: education – science; hydrogeology and hydrology; engineering and environmental geology; miscellaneous and mathematical geology.

Introduction and Background

Children with leukemia, contaminated tap water, municipal wells, manufacturing plants, lawyers, experts, judge, jury, verdict – these are the elements of an undergraduate honors course in which students conduct a mock trial using scientific data from the famous federal trial examining the contamination of municipal wells G & H in Woburn, Massachusetts. The course is unabashedly about applying scientific principles to solve real-world problems. The entire course revolves around the analysis, interpretation, and presentation of scientific data. By the end of the course, students experience first-hand the importance of making sound scientific computations and the need to communicate their interpretations of this work in writing and orally.

The actual lawsuit that is the centerpiece of the course, *Anne Anderson et al. v. W.R. Grace et al.,* is the subject of the award-winning book *"A Civil Action"* by Jonathan Harr (1995) and the critically acclaimed Touchstone Pictures movie of the same name. The book and movie focus on the legal battle waged by eight families, who sued two Fortune 500 companies, W.R. Grace & Company and Beatrice Foods, Inc., alleging that improperly handled industrial chemicals entered the groundwater flow system, were captured by two municipal wells, and prolonged ingestion of the toxic chemicals caused leukemia and other health disorders.

It is the specter of dead children and the spectacle of a mock trial that attract non-science and science majors to enroll. Course prerequisites include one semester each of calculus, chemistry, and geology. In the course, students view the movie; read the book, depositions and trial testimony; examine newspaper articles; analyze geologic, hydrologic, and chemical data; write an expert opinion; construct trial exhibits; give depositions; and testify before a judge and jury. The mock trial represents the culmination of the course and unites the analytical, computational, and communication elements. Enrollment is limited to 12 students, although slightly larger classes could be accommodated by expanding the number of defendants to three by including UniFirst Corporation. (UniFirst settled out of court before the trial.) Class sizes much beyond 15 would make it difficult for everyone to testify at the mock trial.

Municipal wells G & H were constructed in 1964 and 1967, respectively, and are completed in Wisconsinan outwash underlying the Aberjona River and a riparian wetland. The wells were used periodically until May 1979, when they were closed by state order in response to the detection of trichloroethlene (TCE) and perchloroethlene (PCE) in concentrations exceeding US EPA standards. TCE and PCE were classified as probable human carcinogens. The plaintiffs are eight families in eastern Woburn, who received municipal

Data Set	Analysis / Calculations	Interpretations
Drillers' logs	Construction of geologic cross sections of the buried valley aquifer showing spatial distributions of outwash (sand, gravel, silt), lodgement till (silty clay), and wetland deposits (peat and silty sand)	Insight into the depositional history of glacial materials and spatial variations in grain sizes and other physical properties.
Groundwater levels and pathlines	Comparison of potentiometric surfaces, potentiometric profiles, and groundwater pathlines when wells G & H are not used versus when wells G & H are operating	Differences in groundwater discharge areas when wells G & H operate; spatial variations in hydraulic gradients; importance of 3-D view of flow system
Hydraulic conductivities and groundwater travel times*	Simple statistical comparison of K values computed using Hazen's equation and Hvorslev's equation for grain-size samples and slug tests in sands and gravels versus silts and clays; calculation of travel times along pathlines from Grace and Beatrice sites to wells G & H	K values between outwash and till vary by orders of magnitude; travel times are unrealistic if variations in K caused by the distributions of outwash and till are not incorporated in the analysis
Historic streamflow records*	Calculation of flood frequencies and recurrence intervals on the Aberjona River at Winchester, Massachusetts	Insight into how often the Aberjona River floods the wetland at wells G & H
Streamflow gain/loss*	Calculation of streamflow upstream and downstream of wells G & H when wells are operating and not operating	Estimate of groundwater discharge to river when wells not pumping; estimate of streamflow depletion when wells pumping
TCE / DCE concentrations*	Calculation of travel times of TCE and DCE from Grace and Beatrice sites to wells G & H based on 1-D advection dispersion equation	Estimate arrival times of contaminants at wells based on hydraulic gradients, flow velocities, and attenuation

** assignment executed on spreadsheet*

Table 1. Summary of data sets and analyses/calculations performed by students.

water from the wells. High levels of contamination were found on the Grace property (~8000 µg/L TCE) and on the Beatrice property (~ 440,000 µg/L TCE), as well as on other properties in the area. The crux of the trial centers on whether groundwater flows from the Grace and Beatrice properties to the wells and, if so, whether the contaminants reached the wells during their operation from 1964 to 1979. Thus, the actual trial was about science and, in particular, about the application of fundamental concepts of geology, hydrology, and aqueous chemistry to the calculation of contaminant travel times. The direct testimony presented by the expert witnesses focused on their interpretation of the geology and hydrology of the area and on their calculations of groundwater pathlines and contaminant travel times. The cross examinations of the expert witnesses focused on uncertainties in their interpretations and calculations.

It is the interplay between formulating opinions based on scientific reasoning and quantitative analyses, and the presentation and defense of those opinions before a judge and jury that make this mock trial course ambitious and unique. (The list of references includes several that provide information about the geology, hydrology, leukemia cluster, Woburn trial, courtroom procedures, and expert testimony.)

Mock Trial Discovery

Data collected from reports by the US Geological Survey and US EPA, and testimony presented in the trial by expert witnesses are combined into a series of assignments. The assignments are designed to have students explore a variety of geologic, hydrologic, and chemical data and to interpret the data with the goal of formulating their individual expert opinions. The graphs and maps constructed for the assignments later serve as exhibits in the mock trial. The assignments are integrated with field trips to a leukemia research lab, a municipal wellfield, an aggregate quarry, a county landfill, and a wetland. The field trips expose students to geologic deposits, hydraulic properties, and hydrogeologic settings similar to those in the glaciated region around Woburn. Aerial photographs and collections of recent and historic photographs provide students with visual references of Woburn, the wells, river, and wetland.

Each computational assignment requires the students to use the geologic framework of east Woburn as a foundation and to apply various quantitative methods to analyze specific sets of data and to make interpretations based on their analyses. The assignments appeal to the students because they get to explore data sets from the actual trial and because each assignment builds on previous ones to reach a final interpretation as to whether the contaminants from a particular property reached the municipal wells. Thus, most of the lectures and all of the computational assignments are based on teaching the concepts and theory needed to address questions about how groundwater moves, where does groundwater at the defandants' properties flow, and if it flows to the wells, when did the contaminants reach the wells.

Specific assignments include (1) construction and interpretation of geologic cross sections from (simplified) well-log descriptions, (2) construction and interpretation of water-table maps and potentiometric profiles based on water levels measured in 1985 and 1986 during trial discovery, (3) calculation of hydraulic gradients, groundwater pathlines, and groundwater travel times from the defendants' properties to wells G & H, (4) evaluation of stream hydrographs and calculation of flood frequencies and recurrence intervals, (5) interpretation of streamflow gain/loss measurements and calculation of streamflow depletion from pumping wells G & H, and (6) calculation of contaminant travel times to wells G & H accounting for the

effects of mechanical dispersion and chemical retardation. Table 1 lists the data sets used by the students and the types of data analysis and interpretations made as part of their assignments.

All the assignments can be completed using algebra and simple statistics. The necessary theory and equations used in the assignments are presented in class, as are example problems. Most of the equations are algebraic in form or are formulated in algebraic terms. The equations for flood-recurrence interval, hydraulic gradient, Darcy's Law, Theis equation, and groundwater flow velocity are examples. More complex equations, such as the Ogata-Banks equation for one-dimensional advection with dispersion and retardation, which requires students to compute the argument and value for the complementary error function, are presented in the same manner. Students are shown that the solution to a complex equation can be obtained by splitting the equation into parts and solving each part separately. Once the shock of seeing a new function such as *erfc* passes, the students quickly adapt to looking up values of *erfc* in tables – just as they once did for the tangent function. Later, students are shown how to use the intrinsic mathematical functions in spreadsheets to compute *erfc* values. Integral calculus is needed only to understand how some of the equations, such as the Theis, Thiem, and Ogata-Banks equations, are derived, but students are not held responsible for knowing how to derive the equations.

Each computational assignment also contains questions that the students answer. The questions are designed to make the students think about the assumptions and uncertainties in their calculations and to guide them toward making interpretations consistent with the results of their previous assignments. Time is spent describing the difference between calculating a "number" and reaching an "answer" that is consistent with the other parts of the overall problem. For example, a form of Darcy's Law can be used to compute groundwater travel times along the 2500-foot pathline from W.R. Grace to the municipal wells. If students assume that the hydraulic properties of the aquifer materials are uniform along the entire pathline, then computed travel times likely indicate that recharge and chemically non-retarded contaminants at W.R. Grace reach wells G & H in a matter of years – easily within the 15-year period the wells operated. This assumption, however, is contrary to the well-log data they previously used to construct geologic cross sections. If the students partition the calculation of total travel time into pathline segments having different hydraulic properties, then the computed total travel times can exceed the period of time the wells operated. This latter approach requires insight into how geologic heterogeneity affects travel-time calculations, but it produces a reasonable "answer." The former approach ignores the geologic knowledge at hand and produces a "number" that is not realistic. This type of integrated approach to solving quantitative problems makes students realize that their work must be self-consistent with all the data. It also makes them question the assumptions underlying their calculations.

Many of the data sets are provided to students on spreadsheets that contain templates to facilitate making calculations and constructing graphs using the intrinsic mathematical, statistical, and graphing functions. The templates enable plots of the data to "grow" automatically, which lessens the time and frustration many students experience when dealing with new software and allows them more time to analyze and interpret the data seen on the graphs. For example, Figure 1 shows the completed spreadsheet from the assignment dealing with flooding of the wetland. The data shown represent a part of the historic stream-discharge data downloaded by the students from the US Geological Survey web site (http://waterdata.usgs.gov/nwis-w/MA) for the gaging station on the Aberjona River at Winchester, Massachusetts (#01102500), which is three miles downstream of wells G & H. When distributed to the students, the Rank and Recurrence Interval columns are blank. The spreadsheet enables students to sort the peak discharges in descending order of flood magnitude and then to program into specific cells the algebraic equation to compute recurrence intervals. The spreadsheet is set up to construct the graph shown in Figure 2 automatically. Based on this graph, the students are asked to draw inferences about the frequency and magnitude of flood events at wells G & H. Other computational assignments are presented in the same manner with blank columns that the students fill in with appropriate equations and questions to be answered.

The communication assignments, including the trial and trial depositions, are designed to enhance students' written and oral communication skills. These assignments also teach students how to defend their opinions. To gain perspectives different from those of the book and movie, students select one of three essay topics requiring them to read trial testimony and newspaper articles written about the trial by Dan Kennedy of the Woburn Daily Times Chronicle. The topics include (1) comparison of the expert testimony presented by the three hydrogeologists, (2) comparison of the cross examination styles of the three trial attorneys, and (3) comparison of the opinions of Harr and Kennedy concerning the trial proceedings. (Copies of the trial testimony can be obtained at the National Archives and Records Administration Regional Center in Waltham, Massachusetts. Copies of the articles written by Dan Kennedy can be obtained at the Woburn Public Library.)

After this assignment, the students decide which party they want to represent in the mock trial and are introduced to the law students representing their party. The teams normally consist of a geologist, a geochemist, and a hydrologist working with two law students. Following a discussion of professional ethics and a lecture on trial procedures, each student writes an expert opinion. The students also develop a resumé consistent with their area of expertise. After the parties exchange expert opinions and resumés, each student is deposed by the opposing attorneys. The depositions are videotaped and recorded by a court stenographer. Copies of the depositions are prepared and exchanged. The trial is limited in scope by a set of

Date (Water Year)	Peak Discharge	Rank	Recurrence Interval
1979.01.25	1330	**1**	*56.00*
1987.04.07	877	**2**	*28.00*
1982.06.06	850	**3**	*18.67*
1984.05.31	823	**4**	*14.00*
1962.10.07	790	**5**	*11.20*
1969.12.27	748	**6**	*9.33*
1990.08.11	709	**7**	*8.00*
1955.08.19	686	**8**	*7.00*
1968.03.19	649	**9**	*6.22*
1978.01.26	633	**10**	*5.60*
1994.09.23	546	**11**	*5.09*
1972.03.03	540	**12**	*4.67*
1986.03.15	530	**13**	*4.31*
1993.03.29	501	**14**	*4.00*
1990.10.14	496	**15**	*3.73*
1954.09.12	482	**16**	*3.50*
1969.03.25	475	**17**	*3.29*
1976.01.28	461	**18**	*3.11*
1983.03.12	447	**19**	*2.95*
1958.01.26	390	**20**	*2.80*
1956.01.09	378	**21**	*2.67*
1967.05.26	373	**22**	*2.55*
1962.03.13	367	**23**	*2.43*
1948.03.20	358	**24**	*2.33*
1977.03.23	344	**25**	*2.24*

Station: ABERJONA RIVER AT WINCHESTER, MA	
Station number: 01102500	
Latitude (degrees, minutes, and seconds)	422650
Longitude (degrees, minutes, and seconds).	0710822
Drainage area (square miles)	24.70
Base discharge	170.00 cfs
Gage datum (feet above NGVD)	0.00
Water years: October 1, 1939 to September 30, 1998	
Discharge in cubic feet per second	
Discharge in cubic feet per second	

Figure 1. Spreadsheet for computing flood-recurrence intervals showing USGS weir at the Winchester, Massachusetts, gaging station three miles downstream of Woburn wells G & H.

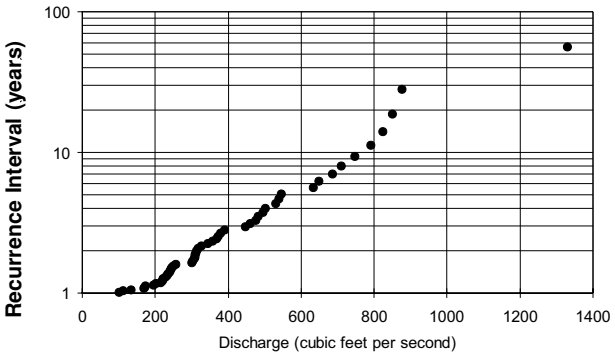

Figure 2. Discahrge versus recurrence interval graph that forms automatically in spreadsheet.

stipulated facts assumed to be in evidence and normally takes about six hours to conduct. Because of the small size of classes (<12 students) in our Honors Program, each student presents direct examination and experiences the rush of adrenalin during cross examination. The trial is held in the moot courtroom in our College of Law before a jury of eight undergraduates. A local judge is asked to preside over the trial, which is videotaped. All testimony is recorded by a court stenographer for later review by the participants. The law students make opening statements, conduct direct and cross examinations of the expert witnesses, and make closing arguments. In the two mock trials conducted, the verdict brought by the student juries differed from that in the actual trial. Each trial takes on its own character based on the personalities of the students involved, their preparation, and competence. A debriefing session between the jurors and the students provides constructive analyses of the students' performances.

Lessons Learned

Course evaluations indicate that the students learned a great deal from the class. Many said they were challenged in more ways than in any other course because they had to teach the science they learned to their attorneys and because the mock trial tested all their skills. The students come away with a front-row view of how conflict is resolved in our legal system. They also develop an appreciation for the various methods scientists use to collect hydrologic and geologic data, the errors inherit in data collection, the techniques used to analyze data, the uncertainties in

data analysis, and the difference between data analysis and data interpretation. The term paper and professional opinion expose students to two different styles of writing – one open, expansive, and full of documentation, and the other guarded, concise, and devoid of supportive references. The students learn how to formulate and defend their opinions, and how to question the opinions of others. Above all, the students see first-hand why it is important to be able to integrate their computational skills with their communication skills.

It is not necessary to be part of a comprehensive university to develop a mock trial course similar to the one described. The mock trial could be held in the county courthouse. Local attorneys could coach political science majors to serve as the mock trial attorneys. The key to developing such a course at a small university or a liberal arts college is to get faculty and students from other departments and local townspeople and officials involved. Photographs, maps, graphs, and data for developing a similar mock trial course can be obtained at http://www.geology.ohio-state.edu/courtroom.

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Food for Thought

The correlation of vocabulary level with intellectual skill applies not only to adults but also to children in preschool, elementary school, and middle school. Only children who possess the communication skills to participate fully in the classroom community at their level are in a position to learn diverse new things within that community. For their level, they have *already* learned how to learn, and are in a position to learn still more. Their readiness to learn new things in a domain is sensitively dependent on what they already know in that domain, as indicated by possession of a relevant vocabulary. Jerome Kagan has well observed that one of the chief learning abilities of children is their aptitude for capturing a range of experiences by the symbolizing function of the mind, a function that most often manifests itself in words. A great many (of course not all) of the intellectual skills of normal children and adults are correlated with their use of words.

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