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ABSTRACT

The effects of two different approaches for teaching the physical science laboratory for non-science majors were compared. The control group had a traditional laboratory with assigned, structured laboratory exercises; the experimental group was subjected to a situation where there was more student involvement in choice of experiment, experimental design and analysis. There were no significant differences identified between the control and experimental groups in "critical thinking ability," understanding of science processes or attitude toward science. Significant improvement in critical thinking ability, as measured by equivalent scores on the Watson-Glaser Critical Thinking Test, was observed for both groups. (Author/TS)

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WSU-CORD

The Wisconsin State Universities Consortium of Research Development

Research Report

DEVELOPMENT OF A MORE FLEXIBLE PHYSICAL SCIENCE LABORATORY PROGRAM FOR NON-SCIENCE MAJORS WITH SUPERIOR HIGH SCHOOL SCIENCE BACKGROUNDS

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Cooperative Research

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and the
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FINAL REPORT

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Whitewater, Wisconsin

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U.S. DEPARTMENT OF
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INTRODUCTORY SECTION

SUMMARY

The primary function of this research was to attempt to compare the effects of two different approaches toward the physical science laboratory. The control group had a traditional laboratory with assigned, structured laboratory exercises; the experimental group was subjected to a situation where there was more student involvement in choice of experiment, experimental design and analysis. There were no significant differences identified between the control and experimental groups in "critical thinking ability", understanding of science processes or attitude toward science. Significant improvement in critical thinking ability, as measured by equivalent scores on the Watson-Glaser Critical Thinking Analysis, were observed for both groups.

INTRODUCTION

Laboratory Science courses have been recognized as an integral part of the college liberal arts curriculum; however, there has been relatively little quantitative research as to the effectiveness of various forms of laboratory instruction. There are several reasons why different approaches toward the laboratory should be compared and evaluated. Some of these are as follows:

1. Some instructors (and students) are not satisfied with the "traditional" form of the introductory laboratory. They feel that the structured experiments where the student only collects data and analyzes it do not give a realistic picture of how science operates. The epithet "cookbook" is frequently used to describe this type of work. (1,2,3)

2. The amount of laboratory work being done in elementary and high school science classes is increasing. If college science classes are to use this superior science background effectively, the college science courses and laboratory programs will have to be reexamined accordingly.

3. The laboratory is expensive in terms of money required for its operation and faculty and student time for laboratory work. With continuing budget pressures, it would seem that a continued emphasis to administrations, regents, etc., upon the importance and unique effectiveness of the laboratory is appropriate.

1. The Proceedings of the Boulder Conference on Physics for Non-science Majors (Commission on College Physics, College Park, Maryland, 1965).
2. J. N. Fox, Laboratory Built on Air, American Journal of Physics, Vol. 35, 789 (1967).
3. B. Fryshman, A Laboratory Course for Nonscience Majors, American Journal of Physics, Vol. 36, 262 (1968).

METHODS

At Wisconsin State University-Whitewater, all students must complete a year of laboratory science. This requirement is met by most nonscience majors by taking Biological Science Foundations 120 and Physical Science Foundations 130. Both of these are 5 credit survey courses with one 2 hour laboratory per week.

For the past few years the enrollment in Physical Science 130 has been divided with students who have had physics, chemistry and at least 3 years of mathematics in high school being assigned to special sections labeled "A" sections.

Academic Year	Total Physical Science 130 Enrollment	Physical Science 130 "A" Section Enrollment
1967-68	2,150	260
1968-69	2,160	250

As shown by the data above, the "A" section enrollment is only a small part of the total program.

This enrollment, although small, is an important part of the student population. The selection criteria implies that these students are well-prepared and of above average ability. Since these students are "special" in this regard, it has been felt that a "special" program should be provided for them so that their superior backgrounds in science can be used and not merely duplicated. The purpose of this research was to attempt to develop a special, more flexible laboratory program for the Physical Science 130 "A" students and to compare this with the existing, more traditional laboratory program which has been in use.

Research Design

The freshman class is arbitrarily divided into two equal parts by the administration during pre-registration with about half of the class being enrolled in Physical Science 130 each semester. The first semester enrollment in the Physical Science 130 "A" was used as the control group. The students enrolled in Physical Science 130 "A" second semester were used as the experimental group. Since the assignment to take Physical Science 130 either first semester or second semester is arbitrary, it was hypothesized that control and experimental groups would not be significantly different at the start of their respective semesters.

There were 4 lecture sections and 8 laboratory sections involved each semester. Each semester half of these were taught by the principal investigator (Frank D. Stekel) and the other half were taught by another faculty member (Shirley L. Stekel). The same textbook, Krauskopf and Beiser's Physical Science, was used by all sections and an effort was made to keep the lecture material as similar as possible.

The students in the control group were subjected to the existing, conventional laboratory program using one experiment per week from the Laboratory Manual produced by the WSU-Whitewater Physics Department Staff. (A list of the experiments performed is in Appendix I.) The students in the experimental group were subjected to a laboratory program where the emphasis was on projects of their choice. Their format was as follows: A subject area for experimentation was assigned for a two week period and a sheet of possible experiment topics was passed out to them in advance of their lab. The students, normally working in groups of 2, would select a topic from this sheet or use their own idea for an experiment in this subject area. A list of these topics is shown in Appendix 2. They would then design their own experiment on this topic with assistance from the instructor with regard to what apparatus was available and, if required, by instruction in its operation. The students had the two 2-hour laboratory periods in which they selected a topic, designed the experiment, collected data and analyzed it, and summarized their results. Most students had chosen their topic before the start of the lab period; many students elected to spend extra time on their projects.

Testing

The students' ACT scores from their college entrance information were available and were used as one measure of their entry behavior in order to check the validity of the hypothesis that the experimental and control groups were initially homogenous.

The Watson-Glaser Critical Thinking Survey, Form Ym, was also administered to each group as a pre-test at the start of the semester.

To measure their behavior at the end of the semester, the following instruments were used:

1. The Watson-Glaser Critical Thinking Survey, Form Zm.

2. The Wisconsin Science Process Inventory.

3. An Attitude Toward Science Survey.

4. An achievement test over the subject matter that was covered; this test was not related directly to the laboratory work.

Initially, the ACT Natural Science Test was also going to be used as a post-test. It was decided that this test would not be administered for the following reasons:

1. The test is rather heavily weighted toward biological science. This would give the second semester students who would have taken the Biological Foundations course (during the first semester) a decided advantage over the students enrolled in the first semester.

2. There were six tests, achievement tests for grading as well as this project's instruments, being administered over the last two weeks of the semester. Spending one more hour on testing during this period did not seem to be desirable.

3. The test was relatively expensive.

Analysis of variance techniques will be applied to the results to attempt to identify any significant differences.

TABLE I

A Comparison of the Control and the Experimental Group's Entry Behavior

	CONTROL				EXPERIMENTAL					
Group Number	1	2	Analysis of Variance		3	4	Analysis of Variance		Analysis of Variance For All Four Groups	
Teacher	FS	SS	Group 1 vs Group 2		FS	SS	Group 3 vs Group 4			
Sample Size	51	54	F	Significant Difference?	48	42	F	Significant Difference?	F	Significant Difference?
	Mean Score				Mean Score					
Watson-Gloser Pre-Test Form YM	71.6	69.8	1.470	NO	72.2	72.6	.048	NO	1.170	NO
ACT Math*	77.8	75.6	.315	NO	76.8	78.6	.185	NO	.205	NO
ACT Natural Science*	69.3	62.8	1.693	NO	70.1	71.3	.050	NO	1.124	NO
ACT Composite*	71.6	69.9	.167	NO	72.3	73.7	.114	NO	.275	NO

*Local, WSU-W percentiles

The above data indicates that the null hypothesis is valid; there is no significant difference between the experimental and control groups initially, and there is no signifficant difference between the instructors' groups. All groups seem to be drawn from the same population.

TABLE II

A Comparison of the Control and the Experimental Groups' Behavior at the Completion of the Treatment

	CONTROL				EXPERIMENTAL					
Group Number	1	2	Analysis of Variance		3	4	Analysis of Variance		Analysis of Variance For All Four Groups	
Teacher	FS	SS	Group 1 vs Group 2		FS	SS	Group 3 vs Group 4			
Sample Size	62	64	F	Significant Difference?	54	45	F	Significant Difference?	F	Significant Difference?
	Mean Score				Mean Score					
Watson-Gloser Post-Test Form ZM	69.5	68.4	.669	NO	68.2	69.7	.779	NO	.484	NO
Wis. Science Process Invent.	37.4	38.6	.371	NO	39.4	41.5	1.218	NO	1.426	NO
Attitude towrd Science Survey	59.3	58.6	.173	NO	59.3	57.4	1.033	NO	.444	NO
Achievement Test*	65.5	67.5	-----	----	63.7	72.3	-----	----	-----	----

*This was not directly related to lab work. The two teachers did not use the same achievement test, although Groups 1 and 3 received the same test and Groups 2 and 4 redeived the same test. For Group 1 vs. Group 3, F = .675, which is not significant; for Group 2 vs. Group 4, F = 4.323, which is significant at the 5% level.

Table II shows the basic analysis of the raw data. On the basis of this, it appears that there were no significant differences between the experimental and the control group on the parameters. The only exception to this was Group 4's improved performance on the final achievement test relative to Group 2: it does not seem likely that this was related to the laboratory.

TABLE III

A Comparison Between the Watson-Glaser Pre-Tests and Post-Tests, Both Scores Converted to the Ym Basis

	CONTROL				EXPERIMENTAL					
Group Number	1	2	Analysis of Variance		3	4	Analysis of Variance		Analysis of Variance For All	
Teacher	FS	SS	Group 1 vs Group 2		FS	SS	Group 3 vs Group 4		Four Groups	
Sample Size	62	64	F	Significant Difference?	54	45	F	Significant Difference?	F	Significant Difference?
	Mean Score				Mean Score					
Pre-Test Watson-Glaser YM	71.6	69.8	1.474	NO	72.2	72.6	.048	NO	1.170	NO
Post-Test Watson-Glaser ZM*	74.8	74.2	.140	NO	73.9	75.2	.602	NO	.248	NO

*Converted To Equivalent YM Scores

This table repeats information presented in Tables I and II, namely that there is no significant difference between aby of the groups on either the Watson-Glaser pre-test or post-test. The Zm form of the test, used as the post-test, is a more difficult form of the test. Here the Zm scores have been converted to the equivalent Ym scores using the conversion table in the Watson-Glaser Critical Thinking Appraisal Manual, (4).

4. Goodwin Watson and Edward Glaser, "Manual for Forms Ym and Zm of the Watson-Glaser Critical Thinking Appraisal", p. 8, Harcourt, Brace & World, Inc., 1964.

TABLE IV

Comparison of Watson-Glaser Pre-Test Scores And (The Equivalent) Post-Test Scores

	CONTROL		EXPERIMENTAL	
Sample Size	126		99	
Analysis of Variance between Watson-Glaser Pre-Test and Post-Tests	F = 13.45	This is significant at the 1% level.	F = 3.072	Not Significant.
T-Test on Pre-Test Post-Test Score Differences	t = 5.21	This is significant at the 1% level.	t = 3.116	This is significant at the 1% level.

This is a continuation of Table III. It shows that one can justify the claim that there is an improvement on the Watson-Glaser Critical Thinking Appraisal between the pre-test and the post-test. There is some ambiguity with the results of the experimental group. A t-test for paired data (5) is significant at the 1 per cent level, so we can reject the null hypothesis that both sets of scores are from the same population, while analysis of variance between the data grouped into just two groups, experimental and control, does not yield an F value large enough to be significant at the 5% level. This ambiguity seems to arise from the higher, although not significantly greater, pre-test scores with the second semester experimental group; it might be due to these students having completed 1 semester of college or simply by chance.

To attempt to clarify this, let us note that there is little difference on the basis of the instructor and simply consider all the pre-tests and post-tests as four groups. These groups, arranged in order of descending mean scores are:

	Mean Score	
Experimental Group Post-Test	74.51	
Control Group Post-Test	74.50)	2.12
Experimental Group Pre-Test	72.38)	
Control Group Pre-Test	70.72	

Note how the Post-Test and Pre-Test results are divided with the Post-Test scores being higher. If the Tukey procedure (6) can be

5. Clinton I. Chase, "Elementary Statistical Procedures", p. 152-155, McGraw-Hill, Inc., 1967.
6. Allen Edwards, "Statistical Methods for the Behavioral Sciences", p. 330-335, Holt, Rinehart & Winston, Inc., 1966.

applied to this data, a significant gap between mean scores is:

at the 5% level $(t_{.05})(\sqrt{2})(S_{\bar{x}}) = 2.32.$

Significance at the 10% level would require a gap of 2.00, so since the gap between the closest pre-test and post-test means is 2.12 it seems safe to say that there is a significant improvement (at least at the 10% level if not the 5%) in general on the Watson-Glaser post-tests over the pre-tests.

The Watson-Glaser Critical Thinking Analysis is divided into five sub-tests. Norms or similar information are not published for these because the authors felt that the sub-tests are not large enough to be reliable. (4) But since these scores would be available, it was decided that they be investigated to see if any information could be obtained from them.

Referring to Table V, for the pre-tests, it appears safe to conclude that all of the samples are from the same population. Group 3 was significantly better than Group 4 on the Recognition of Assumptions sub-test; however, when all four groups were considered together, there was not a significant difference between them.

The post-tests scores are similarly homogenous. Here Group 1 was significantly better than Group 2 on the Evaluation of Assumptions sub-test, but again if all four groups are considered together there is no significant difference between them.

In order to compare the pre-test and post-test scores, one must take into consideration that form Zm is more difficult than form Ym. Table VI shows a comparison between sub-test scores for the control and experimental groups.

4. Goodwin Watson and Edward Glaser, "Manual for Forms Ym and Zm of the Watson-Glaser Critical Thinking Appraisal", p. 9, Harcourt, Brace & World, Inc., 1964.

TABLE V

Analysis of the Scores on the Sub-Tests of the Watson-Glaser Critical Thinking Analysis

		CONTROL				EXPERIMENTAL					
	Group Number	1	2	Analysis of Variance Group 1 vs Group 2		3	4	Analysis of Variance Group 3 vs Group 4		Analysis of Variance For All Four Groups	
	Teacher	FS	SS			FS	SS				
	Sample Size	51	54	F	Significant Difference?	48	42	F	Significant Difference?	F	Significant Difference?
		Mean Scores				Mean Scores					
Pre-test Form Ym	Inference (20)	11.7	11.9	.215	NO	12.0	12.3	.410	NO	.521	NO
	Recog. of Assumpt. (16)	11.4	11.7	.123	NO	13.1	11.5	5.868	Yes, at 5%	2.727	NO
	Deduct. (25)	19.1	18.9	.048	NO	19.3	19.4	.021	NO	.212	NO
	Interpret.(24)	18.8	17.8	3.090	NO	19.3	19.3	.000	NO	3.206	NO
	Eval of Arg (15)	10.2	9.8	1.079	NO	10.2	9.8	1.029	NO	.700	No
Post-test Form Zm	Inference	10.8	10.9	.038	NO	10.7	10.2	.989	NO	.590	NO
	Recog. of Assumpt.	12.6	12.3	.277	NO	12.5	12.3	.225	NO	.174	NO
	Deduction	18.7	18.2 c	.704	NO	18.6	19.1	.757	NO	.770	NO
	Interpretation	17.3	17.1	.032	NO	17.3	17.5	.167	NO	.113	NO
	Eval of Argue	10.7	9.9	4.578	Yes, at 5%	9.9	10.2	.458	NO	1.916	NO

TABLE VI

Analysis of the Sub-Tests of the Watson-Glaser Critical Thinking Analysis

Watson-Glaser Critical Thinking Appraisal SUB-TEST	CONTROL Pre-Test YM (Mean Scores)	CONTROL Post Test ZM (Mean Scores)	CONTROL Analysis of Variance F	CONTROL Analysis of Variance Significant Difference?	EXPERIMENTAL Pre-Test YM (Mean Scores)	EXPERIMENTAL Post Test ZM (Mean Scores)	EXPERIMENTAL Analysis of Variance F	EXPERIMENTAL Analysis of Variance Significant Difference?
Inference (20)	11.8	10.8	6.561	Yes, at 5%	12.1	10.5	22.007	Yes, at 1%
Recognition of (16) Assumptions	11.6	12.4	4.984	Yes, at 5%	12.3	12.4	.019	NO
Deducation (25)	19.0	18.4	1.900	NO	19.3	18.8	1.521	NO
Interpret. (24)	18.3	17.2	7.319	Yes, at 5%	19.3	17.4	22.303	Yes, at 1%
Evaluation of Arguements (15)	10.0	10.3	.994	NO	10.0	10.0	.006	NO

Assuming that the Zm form of the sub-tests is consistently moredifficult than the respective Ym sub-tests, one can categorize the results as follows in Table VII.

TABLE VII

Categorization of Performance on Post-Tests Versus Pre-Tests for the Sub-Tests on the Watson-Glaser Critical Thinking Analysis

	CONTROL	EXPERIMENTAL
SIGNIFICANT IMPROVEMENT	Recognition of Assumptions	
IMPROVEMENT OR NO SIGNIFICANT CHANGE	Evaluation of Arguements Deduction	Recognition of Assumptions Evaluations of Arguements Deduction
NO SIGNIFICANT CHANGE OR DETERIORATION	Inference Interpretation	Inference Interpretation

The same pattern seems to appear with both the control and experimental groups. The largest improvement from pre-test to post-test is in the sub-test on Recognition of Assumptions; this improvement is significant at the 5% level for the control group. There is no significant difference between pre and post tests on Evaluation of Arguments and on Deduction; if the Zm post-test is indeed more difficult here this could also be interpreted as a positive improvement. For the sub-tests on Inference and Interpretation the pre-tests are significantly better than the post-tests. Whether this is little change in student performance coupled with a more difficult post-test or a deterioration in these areas is unclear. Further study would be needed to clear up this point.

Conclusions and Recommendations

The primary function of this research was to attempt to compare the effects of two different approaches toward the physical science laboratory upon students' understanding of the processes of science, their attitudes toward science and their "critical thinking". (7,8) The preliminary analysis of the data has been presented in this report. On the basis of this analysis, with the evaluation instruments used in this research, no significant difference could be detected between the control group and the experimental group.

The first recommendation that could be made is for further study of the raw data. The Attitude Toward Science Survey is not yet finalized and it might be refined to yield a better measure of attitude toward science. (9) Similarly, the Wisconsin Science Process Inventory scores analysis may be improved; some of the 93 questions do not appear to be relevant to their purpose of measuring the students' understanding of sciences processes.

An area which would seem to be fruitful for further study would be to survey the students again about 10 months after they have left the class. This would yield some information relevant to the perishability of the courses influence.

Qualitative Discussion and Comments

The suggestion above arises from the intuitive expectation that there would be some differences between the control and experimental groups. From working with, talking to and evaluating the students one can conclude that these differences are not likely to appear in the area of academic achievement tests or the ability to apply the "scientific method" outside of the laboratory. Rather, it would seem to lie in the area of the students concept of science and the role of experimentation in science. Most of the students in the experimental group seemed to favor this approach toward the laboratory; their most common comment seemed to be that this type of lab was "harder, but made them think". It would seem that this approach, with more student involvement, would result in a better understanding of the role of experimentation in science and in more positive comments with regard to their experience.

7. E.T. Henkel, Undergraduate Physics Instruction and Critical Thinking Ability, Journal of Research in Science Teaching, Vol. 5, 89 (1968).
8. W.C. Schefler, A Comparison Between Inductive and Illustrative Laboratories in College Biology, Journal of Research in Science Teaching, Vol. 3, 218 (1965).
9. Elmer Redford, Assistant Professor, Dept. of Physics, WSU-W, private conversation.

For immediate application to laboratory instruction, one can make some recommendations. One laboratory program to be avoided is the free, totally unstructured laboratory. The sheer logistics of operating our laboratory with projects in specified subject areas was a severe problem. Usually the instructor had to spend the bulk of the period when projects were being started simply finding the appropriate apparatus which was requested and getting the students started. Not enough time was available to really discuss experimental design and problems (instead of the mechanics) of measurement. The above difficulties were all present with small lab sections -- 12 to 16 students in each, working in teams of two. They would be compounded severely if the lab section sizes were the more typical 20 to 26.

It would seem desirable to incorporate the element of student choice, within some structured framework. This might be in the form of a short project at the end of the experiment, an extension of what the student has done in the first part of his experiment, where the student can decide what to investigate and how. This seems to be a valid procedure considering that the control group seemed to do fully as well on all of the evaluation devices in this project. There are certainly other possibilities:

1. A 2 or 3 week project period at the end of the semester;

2. Provide specific apparatus and suggestions but allow the students to work out their own experiments; and

3. Etc.

The "etc." above is limited only by the ingenuity, patience and available time that the instructor can devote to the laboratory.

APPENDIX I

The following is a list of the experiments that were performed by the control group. The experiments are from "Physical Science Foundations 130 Laboratory Manual" of 1968-69 by the Wisconsin State University-Whitewater Physics Department Staff.

1.	105	Indirect Measurement of Piton
2.	108	Scientific Method (A similar experiment was written for the class and passed out on stenciled sheets.)
3.	103	Principles of Measurement
4.	202	Forces in Equilibrium
5.	209	Uniform Acceleration and the Determination of g
6.	207	Changes in Potential Energy
7.	310	Power Output of a Heating Coil
8.	306	Charles' Law
9.	502	Lenses
10.	701	Measurement & Macroscopic Probability
11.	401	Electrostatics
12.	402	Magnetic Field of a Direct Current
13.	503	Diffraction Grating
14.	703	Half-life of a Radioactive Substance

APPENDIX II

The following is a list of the experiments performed by students in the experimental group.

Week	Experiment
1st	Scientific Method (An exercise whose purpose was to illustrate a "scientific method" of investigation and the desired lab report format.)
2nd	103 Principles of Measurement
3rd	A Study of the Motion of a Ball Rolling Down An Inclined Plane - yields displacement, velocity and acceleration.
4th, 5th	Project I - Motion
6th, 7th	Project II - Energy and Momentum
8th	Electrostatics
9th	Magnetic Fields of Direct Current
10th, 11th	Project III - Electricity, Magnetism or Wave Phenomena
12th	Probability
13th, 14th	Project IV - Statistical Studies, Atomic or Nuclear Physics

Project I Topics: Motion

A. Extensive studies with a simple pendulum

1. Over a wide range of lengths.
2. As it moves through a medium other than air.+
3. Measurement of the bob's velocity and acceleration as it swings.+

B. Motion of hoops or spheres as they roll down an inclined plane

1. Effect of varying their mass.
2. Effect of varying their radius.

C. Attempts to show that $F = ma$.

D. Studies of the motion of the Upham Hall elevator.

+Original student idea.

Project II Topics: Energy or Momentum

A. Power output of people under different conditions.

B. The Ballistic Pendulum.

C. Collisions on an Air Track - Momentum Studies.

D. Energy Conservation with a Bouncing Ball - or lack of "Energy Conservation"

E. Work Done Against Friction.

F. Measurement of Specific Heat of Various Substances:

   1. Water, cooking oil.
   2. Milk, tomato soup.+

G. Does hot water freeze faster than cold water?

Project III Topics: Electricity, Magnetism or Waves

A. Studies of resistance of samples:

   1. Temperature dependence for wires or lamps; and
   2. Temperature dependence for solutions.

B. Electrolysis of Water.

C. Electroplating

D. Electromagnetic Induction

E. Simple D.C. Motors

F. Oscilloscopes - their operation and use as a measuring device:

   1. The waveform associated with human voices.+
   2. The waveform produced from a hand-cranked telephone generator.

G. Simple thin lens optics:

   1. Measurement of focal lengths.
   2. Construction of telescopes.

H. Sources of potential difference:

   1. Effect of load on output voltage.

Project IV Topics: Statistical Studies, "Atomic" Physics or Nuclear Physics

A. Radiation shielding in buildings.

B. Measurement of the half-life of various isotopes.

C. Background (cosmic-ray) count over a period of one-week.

D. Absorption of radiation by various materials.

E. Atomic spectra - use of diffraction grating to measure wavelengths of light in a line emission spectrum.

F. Statistical Studies:

1. Involving dice, etc.
2. Human reaction time, using a large sample.