First-year Statistics for Psychology Students through Worked Examples

1. The Chi-Square Test
A Test of Association between Categorical Variables

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I am also indebted to Andrew Legge for help with the formatting of mathematical formulae and symbols.

Most recently, I have become much indebted to Dr Ed Knorr, who very kindly read through the complete typescript and made numerous suggestions and corrections, both large and small.

Any remaining errors or omissions are my responsibility. I would be pleased to receive information from anyone who spots any error, mathematical or otherwise. I can be contacted via e-mail at:

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I should also be pleased to hear from anyone who finds this tutorial helpful, either for themselves or for their students.

Charles McCreery

Introduction[1]

There are usually three complementary methods for mastering any new intellectual or artistic task; these are, in ascending order of importance:

- reading books about it
- observing how other people do it
- actually doing it oneself

These tutorials focus on the second of these methods. They are based on handouts that I developed when teaching first-year psychology students at Magdalen College, Oxford. The core of each tutorial is a worked example from an Oxford University Prelims Statistics examination paper. I have therefore placed this section in prime position; however, in teaching the order of events was different, and more nearly corresponded to the three-fold hierarchy of methods given above:

1. Students were invited to read one of the chapters on the Recommended Reading list, given at the end of each tutorial. They were also expected to attend a lecture on the topic in question at the Department of Experimental Psychology.

2. Students would attend a tutorial, in which we would go through the worked example shown here. They would take away the handouts printed as Appendices at the end of each chapter, which were designed to give structure to the topic and help them when doing an example on their own.

3. They would be given another previous examination question to take away and do in their own time, which would be handed in later for marking.

I am strongly in favour of detailed worked examples; following one is the next best thing to attempting a question oneself. Even better than either method is doing a statistical test on data which one has collected oneself, and which therefore has some personal significance to one, but that is not usually practicable in a first-year course.

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[1] This is a general introduction to a series of three tutorials available here: http://www.celiagreen.com/charlesmccreery.html

I list three books in the General Bibliography at the end of this manual which give worked examples. One of these is Spiegel (1992), in which each chapter has numerous ‘solved problems’ on the topic in question. These worked problems occupy more than half of each chapter. However, the solutions to the individual problems are not as detailed and discursive as the ones I give here.

Another book which is based on worked examples on each of the topics covered is Greene and D’Oliveira (1982), also listed in the General Bibliography. Their examples are as detailed as those I give here. However, they do not cover probability and Bayes’ theorem or Analysis of Variance.

Finally, I strongly recommend the *Introductory Statistics Guide* by Marija Norusis, designed to accompany the statistical package *SPSS-X*, and based on worked examples throughout. Even if the student does not have access to a computer with the *SPSS-X* package on it, this instruction manual contains excellent expositions of all the basic statistical concepts dealt with in my own examples.

The Chi-Square Test

A Test of Association between Categorical Variables

Contents

1. The question[2]

Neyzi, Alp and Orhon (1975) investigated the effect of socio-economic class on physical development of Turkish children. Physical development was classified on a scale of 1 (none) to 5 (fully developed) and the socio-economic class of their parents was assessed on a scale of 1 (highest) to 4 (lowest).

The data were as follows:

Socio-economic class of parents	*Physical development*				
	1	*2*	*3*	*4*	*5*
1	2	14	28	40	18
2	1	21	25	25	9
3	1	12	12	12	2
4	6	17	34	33	6

Plot these data in a meaningful way and report your initial findings.

Stating clearly your hypotheses, carry out an analysis to test for a relationship between physical development and socio-economic class using as many different categories of physical development as possible, and report your conclusions.

Carry out a further analysis comparing those who are fully developed (stage 5) with those who are not (stages 1-4) and report your conclusion.

Provide an explanation for these two conclusions.

For any test where you detect a relationship, report on the nature of that relationship.

[2] The question is taken from the Preliminary Statistics paper for first-year psychology students at Oxford University, Hilary Term, 1999.

2. The answer:

[2.1 How to recognise that this is a chi-square question:

The layout of the data may look superficially like that of a two-way ANOVA, but the data in the cells are raw numbers; to be an ANOVA the entries in the cells would have to be means.

Note also that the measures are both categorical. Class is an ordinal, not an interval, measure. (See Appendix 2 for some points on this distinction.) Physical development might have been a continuous, interval measure, but here it is not; the five categories are discrete and we do not have any information about how they are arrived at, so we can only safely conclude that they are ordinal.]

2.2 Method

The first thing we have to do is collapse some cells. A requirement of the chi-square test is that there should be at least 5 observations in each cell. (The wording of the question contains a hint to remember this when it says 'using as many categories of physical development as possible' in paragraph 4.) We therefore amalgamate columns 1 and 2, and columns 4 and 5, to give the following:

	Physical development		
	2	*3*	*4*
Class			
1	16	28	58
2	22	25	34
3	13	12	14
4	23	34	39

2.3 Plot of class and development

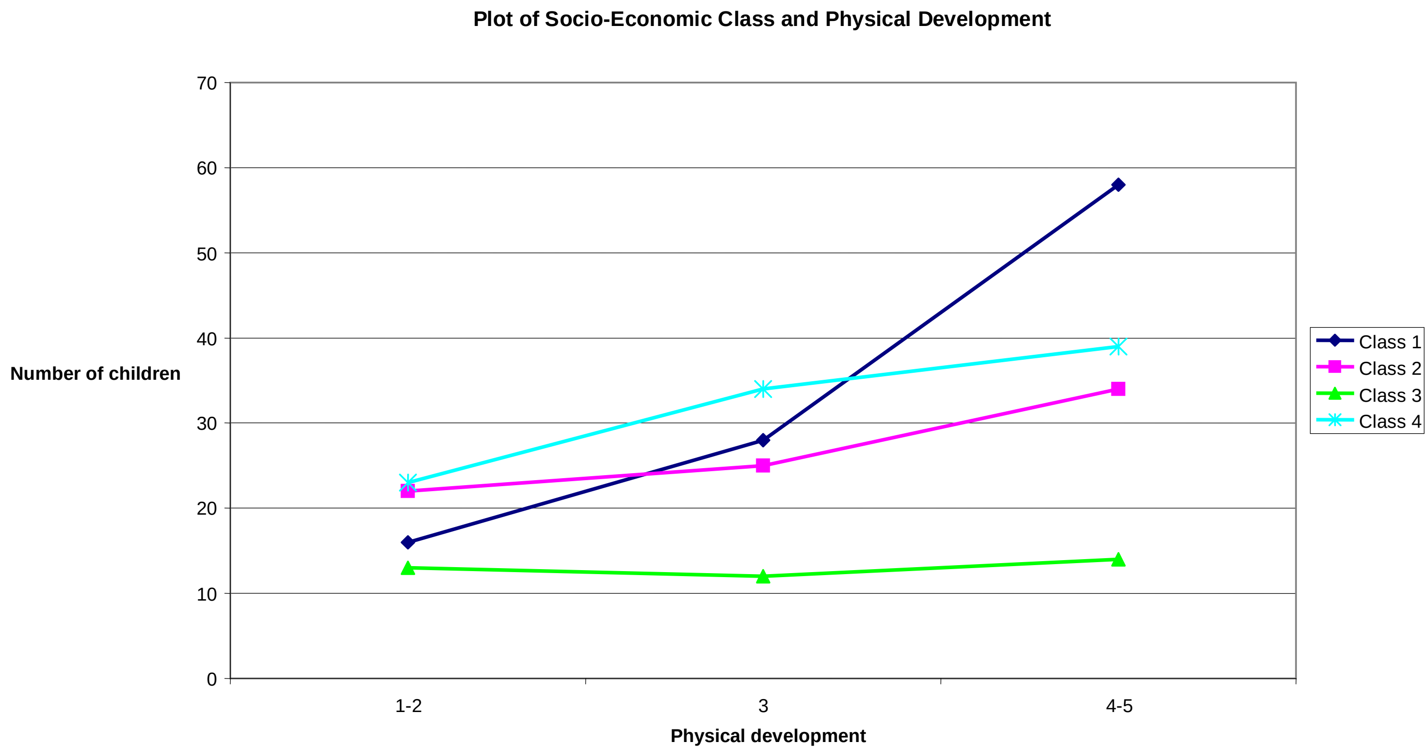
[There are two possible ways of plotting this data: as a stacked bar chart of percentages, or as a line chart. The former is sometimes more revealing, but takes much longer. I recommend a line chart in this case. In fact I recommend line charts for all questions in this paper except those which require you to plot a frequency distribution. The *Descriptive Statistics* type of question has in the past always required a bar chart, and occasionally there are other types of questions which require you to plot a frequency distribution, such as the goodness-of-fit question from Hilary Term 1999.]

The plot (see page 11) reveals that in all classes except Class 3 the number of subjects increases as physical development increases. This is presumably a function of how the population was sampled (i.e., there was a disproportionate number of older children in the sample). The reason for Class 3 not showing this pattern may simply be a chance effect of the total number in this class being smaller than in any of the others.

The most notable effect revealed by the plot is that fully developed children are apparently over-represented in Class 1. This suggests the hypothesis that children in this class develop faster than those in other social classes.

The question does not reveal how socio-economic status was determined, but in the United Kingdom the ordinal value of the classes is negatively correlated with socio-economic status, at least as defined by the commonly used criteria of the Office of Population Censuses and Survey's *Classification of Occupations and Coding Index*. (I.e., Class 1 has the highest rank, and includes professions such as lawyers and doctors; the lowest rank is Class 5, and includes unskilled manual workers).

If we assume that this or a similar classification was used in the Neyzi, Alp and Orhon study, we might hypothesize that the effects found were due to better nutrition, for example, or better living conditions generally.


Plot of Socio-Economic Class and Physical Development
Number of children
70
60
50
40
30
20
10
0
1-2
3
4-5
Physical development
Class 1
Class 2
Class 3
Class 4

``

2.4 Calculation

The next step is to compute the row and column totals, thus:

	Physical development			
	2	*3*	*4*	*Totals:*
Class				
1	16	28	58	102
2	22	25	34	81
3	13	12	14	39
4	23	34	39	96
Totals:	74	99	145	318

Next we have to compute the expected value for each cell, using the formula:

(Row total / Grand total) x Column total

e.g., for the first cell of Row 1 (Class 1, Physical development 2):

(Row 1 total / Grand total) x Column 1 total

= 102/318 x 74

= 0.32 x 74

= 23.74 = 24 rounded to the nearest whole number.

[See Hoel (1976) p. 253 for a good explanation of why this method gives you the expected values (see '4. Recommended Reading' below).]

The resulting table is as follows (expected values are in parentheses):

Physical development

	2	**3**	**4**	**Totals:**
Class				
1	16(24)	28(32)	58(46)	102
2	22(19)	25(25)	34(37)	81
3	13(9)	12(12)	14(18)	39
4	23(22)	34(30)	39(44)	96
Totals:	74	99	145	318

Now we have to apply the formula for the chi-square statistic:

$$\chi^2 = \sum [(O-E)^2 / E]$$

where O = the observed frequency in each category

E = the expected frequency in each category

and the summation is made over all categories.

In this case this gives:

$$\begin{aligned}\chi^2 = &(16-24)^2/24 + (28-32)^2/32 + (58-46)^2/46 \\ &+ (22-19)^2/19 + (25-25)^2/25 + (34-37)^2/37 \\ &+ (13-9)^2/9 + (12-12)^2/12 + (14-18)^2/18 \\ &+ (23-22)^2/22 + (34-30)^2/30 + (39-44)^2/44\end{aligned}$$

$$\begin{aligned}= &2.67 + 0.50 + 3.13 \\ &+ 0.47 + 0 + 0.24 \\ &+ 1.78 + 0 + 0.89 \\ &+ 0.05 + 0.53 + 0.57\end{aligned}$$

$$= 10.83$$

$$\begin{aligned}\text{Degrees of freedom} &= (\text{No. of rows} - l)(\text{No. of columns} - 1) \\ &= (4-1)(3-1) \\ &= 6\end{aligned}$$

For the test to be significant at the 0.05 level, given 6 degrees of freedom, the value for χ^2 has to be at least 12.59 (see Table VII on page 336 of Hoel, 1976, for example). Therefore we cannot reject the null hypothesis of no association between the two variables: parents' socio-economic class and physical development.

Conclusion: any effect in Class 1 as revealed by the plot is swamped by the lack of any effect elsewhere.

2.5 Further analysis

Amalgamating physical development stages 1-4, and recomputing the expected values for each of the new cells by the method described above, gives us the following contingency table:

Class	**Physical development**		
	1-4	**5**	**Totals:**
1	84(91)	18(11)	102
2	72(72)	9(9)	81
3	37(35)	2(4)	39
4	90(85)	6(11)	96
Totals:	283	35	318

Applying the formula:

$$\chi^2 = \sum [(O-E)^2 / E]$$

$$\begin{aligned} &= (84-91)^2/91 + (18-11)^2/11 \\ &\quad + (72-72)^2/72 + (9-9)^2/9 \\ &\quad + (37-35)^2/35 + (2-4)^2/4 \\ &\quad + (90-85)^2/85 + (6-11)^2/11 \\ &= 0.538 + 4.454 + 0 + 0 + 0.114 + 1 + 0.294 + 2.27 \\ &= 8.67 \end{aligned}$$

d.f. = (No. of rows − l)(No. of columns − 1) = 3 x 1 = 3

From a table of the χ^2 distribution (e.g., Table VII on p. 336 of Hoel, 1976), the critical values for χ^2 with 3 degrees of freedom are 7.81 at the 0.05 level and 11.34 at the 0.01 level. In the present case, $0.01 < p < 0.05$ (i.e., our result is significant at the 1 in 20 level).

Conclusion from the test: there appears to be a relationship between the socio-economic status of the parents and the physical development of the children. We reject the null hypothesis of no relationship, at the 1 in 20 level.

2.6 Explanation for the two differing conclusions

Reducing the number of cells in the second version of the test reduces the number of degrees of freedom, and hence the size of the χ^2 value required to achieve significance. In other words we have given ourselves fewer opportunities to pick up discrepancies between observed and expected frequencies, and so the chances of such deviations arising fortuitously are correspondingly diminished.

We may also think of the difference between the two tests as follows: by amalgamating the first four categories of physical development we have counteracted the effect mentioned above, namely that the overrepresentation of Class 1 children in the highest category of physical development and the underrepresentation of Class 4 children in that same category was swamped by the lack of any deviation from expected values elsewhere in the table.

2.7 The nature of the relationship observed in the second test

There appears to be a positive association between physical development and parental socio-economic status. This effect is mainly expressed at the upper and lower extremes of the range, i.e., in Classes 1 and 4. The effect is only apparent when physical development has reached its fullest potential.

[N.B. (1) To fulfil the instructions for the second test we have had to violate the requirement of at least 5 observations in each cell, thus illustrating that this is a practical desideratum, rather than an absolute numerical prerequisite. One might comment on the fact that this requirement had been violated in answering the question, pointing out that any such violation is liable to reduce the validity of the test.

N.B. (2) The format of this question— asking you to do one chi-square test, then collapse some cells and do another to compare with the first—is characteristic of the chi-square questions that have appeared in the Oxford Psychology Prelims Statistics paper of recent years.]

3. Summary of steps in a chi-square test

- **Where expected values are not known:**

1. Draw up a contingency table of the observed values.
2. (a) Compute the column totals. (b) Compute the row totals
3. Assume the null hypothesis of no association between the two variables and work out the expected value for each cell under this hypothesis from the row and column totals. (This is done by applying the formula: Row total/grand total x column total.)
4. Compute the value of chi-square statistic from the formula:

$\chi^2 = \sum[(O-E)^2 / E]$.

5. Work out the degrees of freedom:

d.f. = (No. of rows − l) x (No. of columns − 1).

6. Look up the relevant critical value of *p* in a table of the χ^2 distribution (e.g., in Hoel, 1976, p. 336).

- **To test goodness-of-fit against known expected values:**

1. Draw up a table with the following rows:

   (a) The possible values of *x* (the variable we are interested in)

   (b) The observed frequency for each value (O)

   (c) The expected frequency for each value (E)

   (d) $(O\text{-}E)^2$ for each value

   (e) $(O\text{-}E)^2$ / E for each value

2. Apply the chi-square formula ($\chi^2 = \sum[(O\text{-}E)^2 / E]$) as for a test where the E's are not known.

4. Recommended reading:

a. Hoel, Paul G. (1976). *Elementary Statistics* (4th edition). New York: Wiley. Chapter 10.

b. **OR**: Spiegel, Murray R. (1992). *Schaum's Outline of Theory and Problems of Statistics* (2nd edition). New York: McGraw-Hill. Chapter 12.

c. **OR**: Howell, David C. (1997). *Statistical Methods for Psychology* (4th edition). London: Duxbury Press. Chapter 6.

I recommend Hoel (1976) for this topic. It is quite short, but covers all you need to know about the chi-square test for the Oxford Prelims statistics course. Spiegel also covers the ground, but is rather condensed as usual, with a minimum of discursive discussion. Howell contains considerably more than you need to know. I do not recommend Hays[3] for this topic; it also contains more theory than you need.

[3] Hays, William L. (1994). *Statistics* (5th edition). Orlando, Florida: Harcourt Brace. This is a book sometimes recommended in connection with the Oxford first-year statistics course.

Appendix 1

Summary of some key points about the chi-square test

- **Suitable for categorical data:**

  i.e., data that can be derived from a merely nominal measure (e.g., gender), though ordinal measures are also suitable.

- **Key concept:**

  'contingency table'

- **Practical desideratum:**

  at least 5 observations per cell

- **Two sorts of application:**

  1. where expected values for cells are known (e.g., 'goodness-of-fit' tests)

  2. where expected values are not known (and therefore have to be worked out from the observed data, as in the example above)

- **Yates's correction:**

  Subtract 0.5 from each of the '(OE)' terms, before squaring, on the top line of the formula (see Section 3, above: 'Steps').

  N.B. Yates's correction only applies when (a) dealing with a two-by-two table, and (b) when the numbers are small. If in doubt, apply the formula with and without the correction and quote both results, commenting on any difference. (The χ^2 value after the correction should always be smaller.)

Appendix 2

How to recognise what type of test to do

Type of measure	Nature of data	Examples	Suitable tests
Nominal	Discontinuous/categorical, having no regard for order	Gender Eye-colour	Non-parametric Chi-square
Ordinal	Discontinuous, but rank ordered	Social class Extraversion	Non-parametric, e.g., Chi-square. Parametric if plenty of ranks and normally distributed data
Interval	Truly quantitative and continuous, so intervals all equal; but zero point arbitrary	Fahrenheit Centigrade	Parametric
Ratio	Truly quantitative and continuous; intervals equal, and zero point not arbitrary, so, for example, a doubling of the measure obtained implies a doubling of the underlying quantity measured	Kelvin Age Weight Height	Parametric

General Bibliography

Textbooks of the kind listed below are usually updated every few years. If the reader finds there is an edition later than the one listed here, he or she is recommended to buy the latest version.

Greene, Judith and D'Oliveira, Manuela (1982). *Learning to Use Statistical Tests in Psychology*. Milton Keynes: Open University Press.

Hays, William L. (1994). *Statistics* (5th edition). Orlando, Florida: Harcourt Brace.

Hoel, Paul G. (1976). *Elementary Statistics* (4th edition). New York: Wiley.

Howell, David C. (1997). *Statistical Methods for Psychology* (4th edition). London: Duxbury Press.

Norusis, Marija J. (1988). *SPSS-X Introductory Statistics Guide, for SPSS-X Release 3*. Chicago, Illinois: SPSS Inc.

Spiegel, Murray R. (1992). *Schaum's Outline of Theory and Problems of Statistics* (2nd edition). New York: McGraw-Hill.

Tabachnick, Barbara G. and Fidell, Linda S. (1983). *Using Multivariate Statistics*. London: Pearson Education Ltd.

Charles McCreery is a Research Director of Oxford Forum, an independent association of academics, set up to research and publish in currently neglected areas of psychology, theoretical physics, philosophy and economics.

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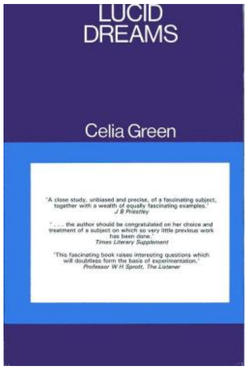

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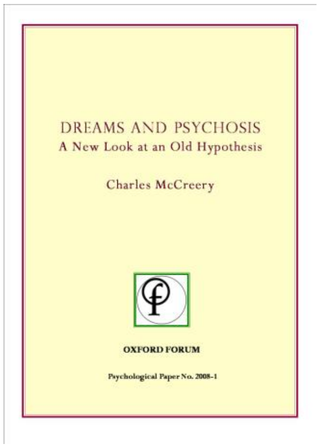

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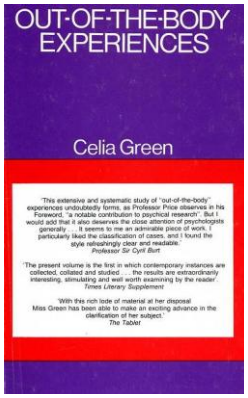

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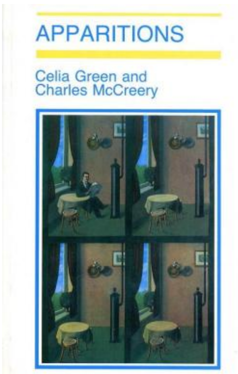

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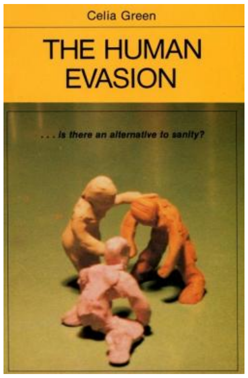

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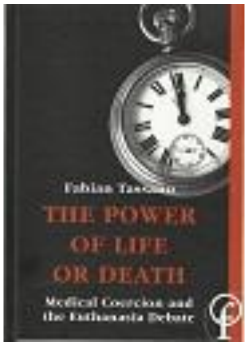

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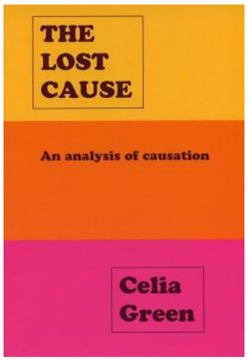

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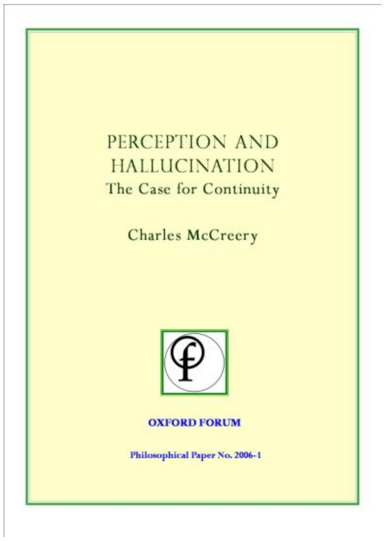

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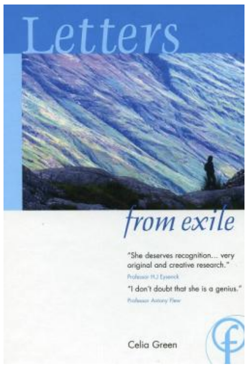

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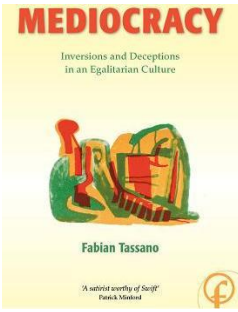

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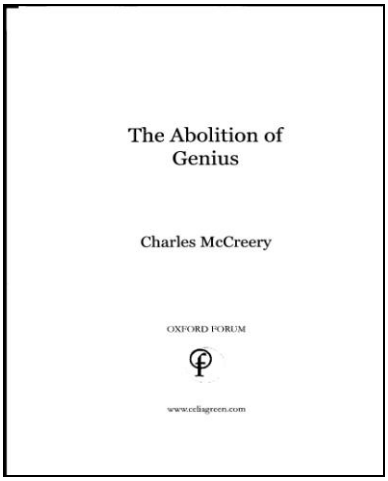
The Abolition of Genius

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