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ABSTRACT

The method presented is a means of determining the communality of the content of two or more texts in the same knowledge domain. The discipline studied was physics. Undergraduate curricula at 59 colleges were studied to determine consensus among the textbooks with respect to general program requirements and specific course offerings. Chapter subheadings were used as a suitable unit for content analysis and comparisons. An index of correspondence was derived, based on the subheadings. This method is a useful technique for indexing consensus in a subject matter domain and is especially useful in disciplines where textbooks are the primary vehicle for learning. Implications for measuring achievement in physics are discussed. (SLD)

A Methodology for Defining Content Domains for Achievement Measures in Specific Disciplines

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Introduction

This paper describes one set of activities conducted as part of a project sponsored under contract with the Office of Educational Research and Improvement (OERI). The initial request for proposals issued by OERI (#R-86-0017) contained the following general description of the goals of the work.

> The Office of Educational Research and Improvement (OERI) seeks a group of studies that will result in models of indicators of college student learning in major academic disciplines and fields. Each study will focus on a single discipline or field and determine how indicator(s) can be constructed so as to account for summative undergraduate learning (of content, methods, assumptions, etc.) in that field, and to help answer the question of what it means to be educated in a discipline. Each study will demonstrate how the methods and/or instruments for determining summative learning can be made sensitive to the diversity of departmental strengths and offerings in the Nation's 4-year colleges and universities.

The RFP also listed a series of more specific tasks to be accomplished by each contractor. These include the following:

> Task 2. Determine what portion of the "summative undergraduate learning" in the field is generalizable to virtually all student majors in 4-year colleges and universities, and what is peculiar to institutions with different sub-field strengths and approaches.
>
> Task 3. Review and analyze existing instruments and methods for assessing "summative learning" in the field.
>
> Task 4. Construct a model of one or more indicators of college student learning in the field.

This paper will describe work related to Task 2.

The discipline selected for study in this project is physics. The approach taken to Task 2 emphasizes the analysis of the undergraduate curricula at a sample of 80 colleges to determine the degree of consensus across institutions with respect to general program requirements and specificc course offerings. In particular, we wished to identify and analyze commonly employed physics textbooks since the content of the undergraduate curriculum is determined to a large extent by the textbooks in common use. However, before examining the

content of specific texts it is important to consider published guidelines for physics programs.

AAPT Guidelines on the Undergraduate Curriculum in Physics

A useful background concerning the undergraduate physics curriculum in U.S. colleges is provided by the Committee on Professional Concerns and Undergraduate Education of the American Association of Physics Teachers (AAPT). The committee has prepared a booklet, AAPT Guidelines for the Review of Baccalaureate Physics Programs which is available through AAPT. The most recent version was published in September, 1987.

The section entitled "Curriculum" suggests that the undergraduate curricula begin with "an elementary course that has at least five subsections: Mechanics, Waves, Heat and Thermodynamics, Electicity and Magnetism, and Optics. ---- A time commitment of at least two semesters is required to teach the five standard subsections; a time frame of three semesters is a better choice if Modern Physics is to be included."

With respect to more advanced undergraduate courses that a physics major ought to take, the Guidelines state, "There should be a vigorous, advanced treatment of topics in Mechanics, Electricity and Magnetism, Thermodynamics and Statistical Mechanics, Optics, Quantum Physics, and Experimental Physics." More specifically, the Guidelines present a detailed listing of topics suggested for inclusion in each of these areas. These are presented in Figure 1.

The curriculum content described in Figure 1 provides an explicit and detailed picture of the course experiences which members of the profession consider to be appropriate for undergraduate majors in physics. In general, our study reveals that the undergraduate curricula at institutions which we surveyed and visited closely parallels that described by the AAPT.

Insert Figure 1 about here

Textbook Survey

To determine the curriculum taught to physics majors in a reasonably quantitative way, we chose to determine what textbooks were used in physics courses taken by physics majors in a sample of schools in the U.S. Textbooks were selected as a measure of the curriculum taught because they provide a basis for inter-institutional comparison which no listing of course titles or descriptions can. Further, we suspected (and our survey bears out) that a relatively small number of textbooks represents fairly well the curriculum taught. We assume in this procedure that the textbooks assigned describe what is actually taught. We have no systematic check on this assumption, though it is consistent with qualitative impressions and information obtained through interviews with over 20 physics faculty members at six different midwestern colleges.

Sample Selection

To obtain a sample of schools for the survey, we selected 80 schools representative of four categories of schools in the U.S.: highly ranked schools with graduate programs (TG), highly ranked schools without graduate programs (TUG), other schools with graduate programs (RG) and other schools without graduate programs (RUG). In practice, we used the American Institute of Physics (AIP) listing of institutions which offer undergraduate degrees in physics for making the selection. To choose the highly ranked (TG) schools offering graduate programs, we took the top 20 as listed in the 1982 ranking sponsored by the Conference Board of Associate Research Councils. To choose the 20 "other" (RG) schools offering graduate programs, we made a random selection of 20 schools from the remaining schools offering graduate programs in the AIP list, weighting each school by the number of physics major graduates in 1985 in making

the selection.

To select the 20 highly ranked schools not offering physics graduate programs (TUG), we used the list of 50 liberal arts colleges participating in the Second National Conference on "The Future of Science at Liberal Arts Colleges" and made a random selection of 20 schools from it, weighting each school by the number of physics major graduates in 1985. This procedure was forced on us by the fact that no reliable ranking of undergraduate physics programs appears to be available. Finally, we made a random selection of 20 more schools not offering graduate programs (RUG) from the AIP list, weighting the schools in the same way.

Each of the 80 schools was sent a letter explaining the project and a form asking for 1) the number of physics majors graduated in the preceding year, 2) a list of courses taken by physics majors and the number of physics majors taking the course in 1985-86, and 3) the textbook used in each course listed. After the letter and the form were sent and the deadline for response had passed, each school which did not respond was telephoned at least once to discover the reason for the failure to respond. In many cases, several follow-up calls were made.

Results of the Textbook Survey

Usable data were obtained from 59 schools, or about 74% of the sample. The number of schools responding in each category is listed below:

Category of School	# of Schools	# 1986 Grads
TG	14	575
RG	13	222
TUG	19	208
RUG	13	78
	59	1083

The 1083 physics majors who graduated from schools in our sample represent approximately 20 percent of the total number of graduates in the country in

1986. Our sample is weighted somewhat in favor of the top rated schools since a higher percentage of schools in that category responded. However, for the purposes of the analyses to be reported in this paper, this is not considered to be an important factor.

To analyze textbooks we divided the reported curriculum into four categories, closely paralleling the recommended advanced undergraduate course patterns as described in Figure 1. The categories were 1) classical and analytical mechanics, 2) electricity and magnetism, 3) thermodynamics and statistical mechanics, and 4) quantum mechanics, modern physics and relativity. Optics and experimental physics were not included because course offerings on these topics were not a part of the curriculum at many responding schools (optics) or no textbooks were employed where courses are offered (experimental). Also, we did not use data on entry level physics courses which are also taken by science students in many other major fields of study.

For each school, data on the number of students taught each of the reported texts was entered on a spread sheet which automatically summed the total number of students reported to be taught from that text and the fraction of all physics majors taught from the book. Within each curriculum category a relatively small number of texts account for the great majority of the students in our sample. To keep the number of texts for further analysis manageable, we decided to restrict attention to texts used by ten percent or more of the students who were physics majors in the schools responding to our survey. Using this criterion, the number of texts retained and the total percent of students using these texts are as follow.

Curriculum Category	# Texts Used By 10% or More	Total % Students Using These Texts
Mechanics	4	92
Electricity/Magnetism	4	75
Thermodynamics/ Statistical Mechanics	2	80
Quantum/Modern/ Relativity	5	117

The total percent exceeds 100 in the last category due to the fact that students frequently take more than one course in that category. For example, a student may take a course in either quantum mechanics or modern physics as a junior and a course in relativity as a senior.

Analysis of Textbook Content

In this section we present a detailed analysis of the content of the most frequently used books in each curriculum category, i.e. those which were reported to be used by ten percent or more of the students from the responding institutions. The purpose of the analysis was to obtain an index of the correspondence of content for each pair of texts within each category. To do this, we examined the chapter subheadings for a given pair of texts. Chapter subheadings were chosen as a suitable unit for content analysis because they represent a convenient compromise between chapters which are too broad and content diverse units and entries in a table of contents which are often much too specific and narrow in content. The typical chapter subheading covers two or three pages of material on a common principle or concept. For each subheading in Text A a search was made of Text B for one or more corresponding chapter subheadings. If a judgment could not be made based upon subheadings themselves, a more detailed examination of content within the sections covered by the subheadings was made. The index of correspondence of Text B to Text A was defined as the number of subheadings in Text A matched by Text B divided by the total number of subheadings in Text A. Conversely, the index of correspondence

of Text A to Text B was defined as the number of subheadings in Text B matched by Text A divided by the total number of subheadings in Text B. The remainder of this section presents the results of the content analysis for each curriculum area.

1. Classical Mechanics

Four textbooks on classical mechanics account for over 90 percent of the students in our sample. These are:

Marion (1970) - 48%
Symon (1971) - 20%
Fowles (1970) - 13%
Kleppner & Kolenkow (1973) - 11%

The summary of the content analysis of these four texts is shown in Table 1 in the form of a matrix with the texts listed in order of popularity. The entries in the diagonal cells of the table give the total number of chapter subheadings in each text. Each off-diagonal cell in the matrix contains the content correspondence index for texts identified by columns as proportions of content in texts identified by rows. For example, we found that the proportion of subheadings in the text by Marion which was matched by those in the text by Symon is .55. The proportion in the reverse direction is .51.

Insert Table 1 about here

Inspection of Table 1 reveals that only the two most popular texts, Marion and Symon, share at least half their content. The text by Fowles shares roughly 1/4 to 1/3 of the content of the Marion and Symon texts, respectively. The text by Kleppner and Kolenkow clearly has little in common with the other three.

2. Electricity and Magnetism

There are four texts on electricity and magnetism that are used by 75 percent of the students from institutions in our sample. The texts are:

Griffiths (1981) - 23%
Purcell (1985) - 18%
Lorrain & Carson (1970) - 17%
Reitz, Milford, & Christy (1979) - 17%

A summary of the content analysis of these four texts appears in Table 2. As with the classical mechanics texts, only one pair of texts in electricity and magnetism, Griffiths and Reitz, et. al., has a substantial overlap in content. Reitz, et. al., accounts for 2/3 of the subheadings in Griffiths whereas Griffiths accounts for roughly 1/2 of the subheadings in Reitz, et. al. The Purcell text appears to have slightly more in common with these two texts than does the text by Lorrain and Corson. The Purcell and Lorrain and Corson texts have extremely small overlap. Overall, the correspondence in content among these four texts is not markedly different than for the four most popular texts on classical mechanics.

Insert Table 2 about here

3. Thermodynamics and Statistical Mechanics

Only two texts on this topic are used by over ten percent of the students at institutions in our sample. Both are quite widely employed and together they account for 80% of the students. The texts are:

Reif, F. (1965). Fundamentals of Statistical and Thermal Physics, New York: McGraw Hill Co. - 43%

and Kittel, C. and Kroemer, H. (1980). Thermal Physics, 2nd (Ed.), San Francisco: W.H.. Freeman and Co. - 37%

An examination of these two texts reveals that they are so fundamentally different in structure that a content analysis using chapter subheadings would be futile. As the title suggests, the text by Reif places heavy emphasis upon statistical models and their application to problems in thermal physics. As noted in the preface, his approach is to present general statistical models

which provide a macroscopic level of description for a wide class of situations followed by illustrative applications. On the other hand, Kittel and Kroemer have structured their book around "standard" topics within the domain of thermal physics. Appropriate statistical models are developed as required for each application. In addition, due to the 15 year difference in the publication dates for the two books, five (out of 15) chapters in the Kittel and Kroemer text deal with applications in more recently developed fields, e.g. cryogenics and semiconductor statistics. Because of these differences no attempt was made to calculate correspondence indices for these two books. (Had such indices been determined there is little doubt that they would be very low.)

4. Modern Physics

Five textbooks were identified for analysis in this category. In this case the books were <u>not</u> selected on the basis of the survey results. Rather, these texts are the ones which were used at six midwestern institutions which were visited prior to the completion of the textbook survey. (In each case we certified that the book was the required text for the junior level course taken by all physics majors.) As subsequently revealed by our survey, these texts do include the most popular one and, in aggregate, account for over 2/3 of the students enrolled in modern physics at the institutions in our survey sample. The textbooks and percents based upon survey results are as follow:

Beiser (1981) - 3%
Eisberg & Resnick (1974) - 43%
Krane (1983) - 6%
Tipler (1978) - 8%
Weidner & Sells (1973) - 8%

Table 3 shows the results for the content analysis of these texts. In this case the indices are much higher than for classical mechanics and electricity and magnetism. The values range from .44 to .80 with an average value of .65. No single book stands out as different from the others. The text by Tipler is

most representative of this category since it exhibits the highest similarity in content to the other four.

Insert Table 3 about here

Implications for Measuring Achievement in Physics

Any instrument proposed as a measure of achievement in undergraduate physics would need to sample the major curricular domains in a representative fashion. The relative weight assigned to each area of coursework might be determined by any of a variety of schemes, e.g. according to the typical distribution of credit hours in each category. The determination of what outcomes to sample within each domain is typically a matter of "expert opinion" as to what is important.

Authors of widely employed texts certainly qualify as experts in the subject matter domain. Where there is a demonstrable consensus among textbook authors the job of sampling learning outcomes in the domain is somewhat easier. The test constructor may select from a large set of concepts, principles, and skills with a high degree of certainty that students have been exposed to them in their coursework. This seems to be the case in the domain of modern physics.

However, in the domains of classical mechanics and electricity and magnetism, the test constructor is faced with a more difficult job in selecting outcomes which are equally familiar to all students. In mechanics, the best bet would be to select outcomes common to the texts by Marion and Symon. These would be familiar to the largest number of students -- about 2/3 of those in our sample. However, the likelihood that these outcomes would be appropriate for students who used the Kleppner and Kolenkow text is quite low.

Similarly, only two texts in electricity and magnetism (Griffiths and Reitz, et. al.) provide a reasonable framework for sampling outcomes in that

domain. Unfortunately, students who studied with the other texts have a relatively low probability of being familiar with these outcomes.

Summary

The methodology illustrated in this paper provides a means of determining the communality of the content of two or more texts in the same knowledge domain. It is a useful technique for indexing the consensus in a subject matter domain and may be especially appropriate in disciplines where textbooks are the primary vehicle for student learning. In domains where the indices of content communality are low, the design of measures with acceptable content validity is made more difficult.

Figure 1

Description of Advanced Undergraduate Courses Recommended for Physics Majors

Mechanics: The mathematical level of the course should require the use of differential equations. Central forces should be studied through at least the development of Kepler's laws. The study of systems of particles should pursue the consequences of the conservation of energy, momentum, and angular momentum; the latter should include the use of the inertia tensor. The analysis of rigid body motion should include the application of Euler's equations. Lagrangian mechanics should be treated in sufficient depth for its application to small oscillations and coupled oscillators.

Electricity and Magnetism. The mathematical level of this course should require the use of field operators and vector integral theorems. The treatment of electrostatics should encompass Coulomb's law, the electrostatic field and potential, the Laplace and Poisson equations; electric dipoles; multipole expansions of potentials; electrostatic energy and force; capacitance; polarization; dielectrics; and the electric displacement field. The topics of electric current, Ohm's law, and the continuity equation will lead to discussions of magnetism, including the magnetic induction field; the Biot-Savart law; Ampere's law; magnetic energy, force, and torque, magnetization; and the magnetic field. Maxwell's equations should be considered essential components of this course and they should be applied to simple geometries (e.g., plane waves in an infinite, non-conducting medium). Complex waves could also be introduced. If time permits, relativistic electrodynamics could be briefly considered.

Thermodynamics/Statistical Mechanics: A thorough grounding in the concepts of temperature, work, specific heat, compressibility, and entropy should result from this course. The laws of thermodynamics, from the zeroth to the third should be discussed, with a thorough discussion of the import of the second law. The four thermodynamic generating functions (internal energy, enthalpy, Helmholtz function, and Gibbs function), together with Maxwell's relations, should be used to solve practical problems such as gas laws, engines, radiation, and phase transitions. The kinetic theory of gases, partition functions, and, as possible, ensembles are covered. Here is the student's first exposure to Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein statistics

Optics: Both geometrical and physical optics should be included. Enough time should be spent on thin lenses and mirrors to provide an understanding of simple optical systems and such concepts as magnification, entrance and exit pupils, and stops. The treatment of physical optics should include a discussion of two-beam and multiple-beam interference, diffraction at apertures, and the application of those principles to simple interferometers, double-slit diffraction, the diffraction grating, and diffraction-limit resolution. Polarization and reflection should also be included. As time permits, there should be selective coverage of thick lenses, lens aberration, lens design, vision, color, ray tracing, birefrigence, spectroscopy, scattering, transfer functions, radiometry, and photometry. Some mention of lasers, holography, fiber optics, gradient-index optics, phase conjugation, and optical computing would tie the course to current technological development.

Quantum Physics. The historical foundations of quantum physics, blackbody radiation, Compton scattering, the Davisson-Germer experiment, and the Bohr-Sommerfeld model of the atom should be established (if not previously given the student in a modern physics course). The quantum physics course should include in-depth applications of the Schrödinger equation to one-dimensional problems such as the square-well potential, barrier scattering and tunneling, and the harmonic oscillator. The treatment of quantized angular momentum should include some elementary work with operator methods and commutators. Three-dimensional problems should, at a minimum, describe the hydrogen atom and should include relativistic corrections. If this course is extended into a second semester there should be applications of essential quantum concepts to major fields of contemporary physics, e.g., multiple particle wavefunctions vis-a-vis elementary quark models, shell theory applied to nuclear models, group theory, and matrix methods applicable to the theory of solids.

Experimental Physics: The goal of this laboratory course is to give the student experience with real-world apparatus such as lasers, high field magnets, detectors, radioactive sources, vacuum equipment, and sophisticated electronics (at the level of lock-in amplifiers and multichannel scalers). The schedule should be a blend of classic experiments illustrating concepts from electricity and magnetism and quantum physics (the Franck-Hertz experiment, Zeeman effect with ions, measurement of the speed of light, etc.) as well as experiments designed to convey the flavor of contemporary experimental physics Examples of the latter are experiments on tunnel junctions, angular correlation of gamma rays, nuclear decay spectroscopy, and magnetic resonance spectroscopy Special attention should be given to written communication of scientific information (see the *AIP Style Manual*).

Table 1

Summary of Content Analysis of
Classical Mechanics Texts Using Chapter Subheadings

	Marion	Symon	Fowles	Kleppner/ Kolenkow	Row Average p
Marion	125	.55	.26	.09	.30
Symon	.51	124	.32	.08	.30
Fowles	.26	.35	131	.17	.26
Kleppner/ Kolenkow	.11	.14	.18	87	.14
Column Average p	.29	.35	.25	.11	.25

Marion, J.B. (1970). Classical Dynamics of Particles and Systems, (2nd Ed.). New York: Academic Press.

Symon, K.R. (1971). Mechanics, (3rd Ed.). Reading, MA: Addison-Wesley Publishing Co.

Fowles, G.R. (1970). Analytic Mechanics, (2nd Ed.). New York: Holt, Rinehart and Winston.

Kleppner, D. and Kolenkow, R.J. (1973). An Introduction to Mechanics. New York: McGraw-Hill.

Table 2

Summary of Content Analysis of
Electricity and Magnetism Texts Using Chapter Subheadings

	Griffiths	Purcell	Lorrain/ Corson	Reitz/ Milford/ Christy	Row Average p
Griffiths	146	.20	.18	.66	.35
Purcell	.25	116	.13	.26	.21
Lorrain/ Corson	.18	.08	140	.16	.14
Reitz/ Milford/ Christy	.49	.17	.18	160	.28
Column Average p	.31	.15	.16	.36	.24

Griffiths, D.J. (1981). Introduction to Electrodynamics. Englewood Cliffs, NJ: Prentice-Hall.

Purcell, E.M. (1985). Electricity and Magnetism: Berkeley Physics Course - Vol. 2, (2nd Ed.). New York: McGraw-Hill Co.

Lorrain, P. and Corson, D. (1970). Electromagnetic Fields and Waves, (2nd Ed.). San Francisco: W.H. Freeman and Co.

Reitz, J.R., Milford, F.J., and Christy, R.W. (1979). Foundations of Electromagnetic Theory, (3rd Ed.). Reading, MA: Addison-Wesley Publishing Co.

Table 3

Summary of Content Analysis of
Modern Physics Texts Using Chapter Subheadings

	Beiser	Eisberg/ Resnick	Krane	Tipler	Weidner/ Sells	Row Average p
Beiser	131	.63	.61	.80	.68	.68
Eisberg/ Resnick	.53	126	.74	.71	.51	.62
Krane	.63	.68	99	.79	.70	.70
Tipler	.66	.63	.67	90	.44	.60
Weidner/ Sells	.72	.60	.65	.65	89	.66
Column Average p	.64	.64	.67	.74	.58	.65

Beiser, A. (1981). Concepts of Modern Physics, (3rd Ed.). New York: McGraw-Hill.

Eisberg, R. and Resnick, R. (1974). Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles. New York: John Wiley & Sons.

Krane, K. (1983). Modern Physics. New York: John Wiley & Sons.

Tipler, P.A. (1978). Modern Physics. New York: Worth Publishers, Inc.

Weidner, R.T. and Sells, R.L. (1973). Elementary Modern Physics, (2nd Ed.). Boston, MA: Allyn & Bacon, Inc.