RESEARCH-BASED LEARNING IN UNIVERSITY PHYSICS: USING AUTHENTIC DATA ON INTERPOLYMER COMPLEX FILMS TO DEVELOP ANALYTICAL SKILLS IN FUTURE SPECIALISTS

Jurakulov Sanjar
Doctoral student, Asia International University, Bukhara, Uzbekistan

Abstract. The paper proposes a model for integrating the results of the author's own materials-science research into the university physics course. The model uses real experimental data from a monograph on interpolymer complex films based on sodium carboxymethylcellulose (Na-CMC) and polyacrylamide (PAA) as a case for teaching measurement analysis, data modelling and scientific argumentation. Two datasets, solution viscosity and tensile properties of the films, are turned into guided inquiry tasks in which students test the additivity assumption, compare secant and initial moduli and justify conclusions in writing. The article describes the structure of the model, gives worked examples computed from the published data and outlines a quasi-experimental design for evaluating its effect. The effectiveness of the model has not yet been tested in a classroom; the expected outcomes are formulated as hypotheses.

Keywords: research-based learning, authentic data, physics education, polymer films, data analysis, scientific reasoning, higher education.

1. INTRODUCTION

Introductory physics courses at universities are often built from idealised textbook problems: frictionless planes, ideal gases and point masses. Students who solve such problems learn procedures, yet they rarely meet the features of real measurements: scatter, systematic error, non-monotonic dependences and results that contradict the simplest model [1, 2]. As a result, graduates can apply a formula but have difficulty judging whether a dataset supports a claim.

The idea of research-based (inquiry-based) learning is that students work with the same kind of evidence and the same kind of questions as researchers do [3, 4]. Meta-analyses show that active, inquiry-oriented instruction raises examination performance and lowers failure rates compared with lecturing alone [5, 6]. The practical obstacle is the supply of suitable material: real datasets from laboratories are usually unavailable to the teacher, or too complex for a first course.

Teachers who are themselves researchers have an advantage here. The monograph by the author [7] reports the preparation and characterisation of interpolymer complex films from two industrially produced polyelectrolytes, Na-CMC and PAA, and contains compact, internally consistent data on viscosity and mechanical behaviour. These data concern concepts that every physics course covers (internal friction, stress, strain and Young's modulus), but their behaviour is not textbook-like. This makes them a convenient case for teaching critical data analysis. The aim of the study is to describe a teaching model based on such data and to substantiate a design for its evaluation.

Source data. The published data in [7] were used without modification: the efflux time and the dynamic viscosity of Na-CMC/PAA solutions mixed in ratios from 9 : 1 to 1 : 9 (capillary viscometer, reference viscosity of water 1.002 mPa·s), and the Young's modulus E, the tensile stress at break σ and the strain at break ε of the films (SHIMADZU AG-X Plus testing machine, specimens 100 × 15 mm,

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thickness 0.18–0.22 mm, 20 °C). The viscosities of the pure solutions were 0.718 mPa·s (Na-CMC) and 2.1255 mPa·s (PAA).

Structure of the model. Each topic follows four stages, adapted from the experiential learning cycle [8]: (1) concept stage – the instructor introduces the physical quantity (for example, viscosity as internal friction between fluid layers); (2) data stage – students receive the table and compute derived quantities with a spreadsheet or a short Python script; (3) modelling stage – students formulate a simple model (the additive mixing rule, or Hooke's law $\sigma = E\varepsilon$), test it against the data and measure the deviation; (4) argument stage – students write a short claim–evidence–reasoning explanation and discuss it in a group.

Evaluation design. A quasi-experimental study is planned for one semester with an experimental and a control group of at least 25 students each. The control group solves traditional problems on the same topics. The outcomes are: (a) normalised gain on a concept test [9, 10]; (b) quality of written arguments scored with a four-level rubric by two independent raters (inter-rater agreement is checked with Cohen's kappa); (c) a short attitude questionnaire. Group differences are tested with the independent-samples t-test or the Mann–Whitney test, and the effect size is reported as Cohen's d.

Worked task 1: the additivity assumption. Students are asked: if two solutions were simply mixed, what viscosity would be expected? The linear mixing rule $\eta = x\eta_1 + (1 - x)\eta_2$ gives the "expected" values in Table 1, to be compared with the measured ones. At a Na-CMC : PAA ratio of 8 : 2 the rule predicts 1.00 mPa·s, whereas 2.39 mPa·s was measured, i.e. 2.4 times higher; at 1 : 9 the prediction is 1.98 mPa·s and the measured value is only 0.70 mPa·s. The measured viscosity is even above that of both pure components in the range 6 : 4 – 9 : 1. Thus the simplest model fails in both directions, and the students must look for a physical reason: the formation of interchain associates changes the hydrodynamic volume of the macromolecules, as discussed in [7].

Table 1. Measured and additive viscosity of Na-CMC/PAA solutions (data from [7])

Na-CMC : PAA	η measured, mPa·s	η additive, mPa·s	Ratio
1 : 9	0.698	1.985	0.35
4 : 6	1.563	1.562	1.00
5 : 5	2.011	1.422	1.41
8 : 2	2.391	0.999	2.39
9 : 1	2.195	0.859	2.56

4. CONCLUSION

The experimental results of a monograph on Na-CMC/PAA interpolymer complex films can be converted into a set of guided inquiry tasks on additivity, definitions of moduli and property–application reasoning. The proposed four-stage model (concept, data, modelling, argument) brings the physics course closer to real research practice and uses data that the instructor can explain in depth. The next step is the planned quasi-experiment; only its results will show whether the model improves conceptual understanding and scientific reasoning.

Expected outcomes and limitations. The model is expected to (1) increase normalised gain on concepts of stress, strain and internal friction, because the tasks require the active construction of explanations [5, 6, 11]; (2) improve the quality of evidence-based argumentation; and (3) develop the habit of questioning a model rather than applying it automatically. These expectations are hypotheses.

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The main limitations are the narrow materials-science context, which may be unfamiliar to students of non-chemical programmes, and the single-source origin of the data. They are reduced by short introductory notes and by giving students the opportunity to repeat a simple viscosity measurement in the laboratory.

Worked task 2: which modulus? In the mechanics dataset students compute the secant ratio σ/ε and compare it with the tabulated Young's modulus. For pure Na-CMC (σ = 32 MPa, ε = 2.18 %) the ratio is about 1470 MPa, while E = 511 MPa. The difference is explained by the definition: E is the slope of the initial linear part of the stress–strain curve, whereas σ/ε at break includes the softer region before fracture. For the 30 : 70 film the two values nearly coincide (2500 and 2591 MPa), because the material is brittle and its curve is almost linear up to fracture. The task trains students to read a definition carefully and to relate a number in a table to the shape of a curve.

Worked task 3: non-monotonic design. The same table shows that adding 10 % of PAA lowers E from 511 to 121 MPa and σ from 32 to 4.19 MPa, whereas the 30 : 70 composition reaches E = 2591 MPa but fails at 0.5 % strain. Students are asked to choose a composition for a flexible wound dressing and another for a rigid protective coating and to justify the choice, which develops the habit of linking measured properties to an application.

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