

Design guidelines for adapting scientific research articles: an example from an introductory level, interdisciplinary program on soft matter

Elon Langbeheim^{*,§}, Samuel A. Safran[§], Edit Yerushalmi^{*}

^{*}*Department of Science Teaching, Weizmann Institute of Science, Rehovot, 76100 Israel*

[§]*Department of Materials and Interfaces, Weizmann Institute of Science, Rehovot, 76100 Israel*

Abstract. We present design guidelines for using Adapted Primary Literature (APL) as part of current interdisciplinary topics to introductory physics students. APL is a text genre that allows students to comprehend a scientific article, while maintaining the core features of the communication among scientists, thus representing an authentic scientific discourse. We describe the adaptation of a research paper by Nobel Laureate Paul Flory on phase equilibrium in polymer-solvent mixtures that was presented to high school students in a project-based unit on soft matter. The adaptation followed two design strategies: a) Making explicit the interplay between the theory and experiment. b) Re-structuring the text to map the theory onto the students' prior knowledge. Specifically, we map the theory of polymer-solvent systems onto a model for binary mixtures of small molecules of equal size that was already studied in class.

Keywords: APL, NOS.

PACS: 82.35.Lr

INTRODUCTION

The introduction of authentic texts in advanced courses for high school students is not uncommon in the social sciences¹ where it serves to represent the culture and practice of a field. Similarly, in order to expose students to authentic scientific practices and current discoveries, scientific papers have also been recently introduced as part of biology and chemistry high school curricula^{2,3}. However, since scientific papers (referred to as "primary" literature) assume that the reader has substantial background, the aforementioned high school curricula use adapted articles (termed "Adapted primary literature" (APL)), that make the original text more accessible to students, while maintaining its core features, which represent authentic discourse among scientists.

At the *introductory physics* level, adapted primary literature has been scarcely implemented⁴, probably, because understanding even APL requires prior knowledge that is far beyond the physics studied in introductory courses. However, the growing interest in project-based learning⁵ brings into focus the challenge of training students to communicate in the language of scientific research; adapted primary literature can serve as a scaffold for the development of critical reading skills needed when encountering literature related to the project and later on to support writing of final papers. In addition, reading Adapted Primary Literature can promote scientific literacy²

which is a learning objective in and of itself. It is thus important to develop criteria for adapting physics research papers and to investigate student learning in this context.

In this paper, we discuss our use of an adapted, primary literature article as part of a project-based unit in a course on the physics of soft and biological matter for interested high school students.

In the following, we first describe the context of the soft matter course in which the APL was implemented; we then discuss the guidelines for the adaptation and how they were implemented. Finally, we provide preliminary analysis of student' comprehension of the purpose of the text.

APL: GENERAL DESIGN GUIDELINES

Yarden, Brill and Falk² mention two educational objectives for introducing APL: a) the text should convey new and interesting content and develop knowledge of the subject area; b) the paper should serve as a vehicle for developing scientific literacy, reflecting an authentic 'story' of science in its making. They propose three criteria for choosing a paper for the biology high school curriculum: The paper should be *relevant* to the topics of research in biology; it should present a relatively *simple research approach* and should contain *straightforward, visual representations* of the results. Similar considerations are recommended for adapting a physics research paper. In addition, due

to the hierarchical nature of physics, a major consideration in choosing an article is to find one in which the theoretical sections can be mapped to models of related systems that were previously presented in the course.

After choosing the paper, the adaptation of the paper requires several adjustments in order to make the paper accessible to the students. The considerations that shape the adaptation include an emphasis on the main argument of the paper such as its stated purpose, a link between the paper and student prior knowledge, and exclusion of non-essential details that might distract the reader. Similar to Falk, Brill, and Yarden⁶, and taking into account that in physics the difficulties in comprehension of the text are compounded in the theoretical sections, we suggest four major guidelines for the adaptation of primary literature to the level of introductory students: (1) In the introduction, the purpose of the article should be made explicit with respect to the contribution of the study to the scientific development of the field. (2) In the experimental section, the scientific methods should be expounded, while unnecessary technical information should be omitted. (3) In the results section, findings that do not directly relate to the main purpose of the research should be omitted. (4) The theoretical section of the paper should be restructured and mapped onto previous studied models and principles. These guidelines provide a general template for adapting primary scientific literature; their precise implementation depends on specific characteristics of the paper and will be discussed in the following section.

CONTEXT

We used APL as part of an extra-curricular program offered to capable and interested high school students at an off-school science education center in Israel. The program was designed to stimulate the curiosity of students by introducing the physics of soft and biological matter - a dynamic, interdisciplinary field that demonstrates the power of statistical thermodynamics to simplify and analyze systems important in both chemical technology and as models of biological systems⁷. These systems, such as fluid mixtures, colloids, polymers and surfactants are characterized by inter-particle interactions whose energies are comparable to the thermal energy at room temperature. The course was offered on a voluntary basis to 11th and 12th grade students and consisted of 22 bi-weekly afternoon meetings each 2.5 hours long. The program included most of the topics that are traditionally part of the thermodynamics section of the introductory physics course from a microscopic, statistical perspective. In addition, the program introduced the modeling and statistical

thermodynamic analysis of phase separation of binary mixtures, interfacial tension, self-assembly and polymer conformations. The course culminated with an independent, experimental inquiry project intended to develop students' ownership of their learning.

The APL discussed here was introduced as paradigm for the writing of a scientific report on the inquiry project carried out by the students, in which the experimental findings were expected to be related to the theory presented in the course.

APL IN THE SOFT MATTER COURSE

The paper chosen for adaptation was: A. R. Shultz and P. J. Flory, "Phase Equilibria in Polymer-Solvent Systems", *J. Am. Chem. Soc.* 74, 4760 (1952). This article presents experimental evidence for the Flory-Huggins theory of polymers in solvents, for which Flory was awarded a Nobel Prize. This theory extends the theoretical analysis of binary mixtures of two particles of equal size (which was presented previously in the course) to mixtures of two particles whose sizes can be very different (long chain macromolecules in small molecule solvents). The difference in the macroscopic behavior of these two types of mixtures manifests itself in the shape of their phase diagrams. The phase diagram distinguishes two regions in the two-dimensional space of temperature and mixture composition that correspond either to two phases (one with a high and the other with a low concentration of polymer) that coexist in equilibrium or to a uniform, mixed phase. The line that separates the mixed/phase separated regions can be determined experimentally by light scattering, since near the transition from mixed to phase separated, micron sized droplets form and the light passing through the system gets scattered.

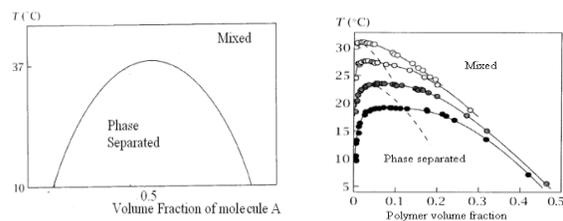


FIGURE 1. Symmetrical (left) and polymer (right) phase diagrams adapted from Dill and Bromberg (2003)⁸. In the right figure the different phase diagrams demonstrate the effect of the length of the polymer on the shape of the diagram.

While in binary mixtures of molecules with similar sizes, the phase diagram is fairly symmetrical, in polymer solvent mixtures it can be sharply skewed. The maximum temperature at which phase separation may be observed (termed the critical temperature), can occur at very small volume fractions (compositions) of polymer. In binary mixtures of similarly sized

molecules the critical point is fairly close to a volume fraction of $\frac{1}{2}$ as shown in figure 1.

The shape of the macroscopic phase diagram is explained theoretically by minimizing the free energy which combines the entropy and internal energy of the system. Mathematical expressions for how these quantities vary with temperature and composition require microscopic models for the particle configurations and interactions; in our presentation we constrained the particles to lie on a lattice. Phase separation occurs in binary mixtures when the interactions between the two unlike particles (monomer and solvent) are unfavorable compared with particles of the same type; in addition, the difference in internal energy resulting from the interactions, must dominate the decrease in the entropy loss due to demixing. On the other hand, when the entropy is dominant, the two components mix in a single phase. In mixtures of molecules whose sizes are identical, the mixing entropy is symmetric with respect to the composition of the system. However, since the polymer chain comprises $N \gg 1$ monomers, its translational entropy involves the concerted displacement of the N monomers in each chain; this contribution (per monomer) is smaller than the translational entropy of the small, solvent molecules by a factor of $1/N$ and creates an asymmetry in the entropy with respect to concentration⁹.

Since the students in the course already studied the theory of binary mixtures of similarly sized molecules, a central consideration in the adaptation of the paper was the mapping of the theory of polymer-solvent mixtures onto the previously studied theory. The following adjustments were made according to the aforementioned guidelines:

1. Introduction: To clarify the purpose of the article, relate it to the students' prior knowledge, and spark their interest, we added to the original statement of purpose of the study, shown in figure 2. We also added a section shown in figure 3 that explicates the puzzle of why the phase diagrams of polymer-solvent mixtures are asymmetric (in contrast to the symmetric diagrams of molecules whose sizes are equal).

The theory of polymer solutions developed some years ago^{5,6} predicts a high degree of dissymmetry in the phase equilibrium diagram which, qualitatively at least, is in accord with the observations. The present study of phase relations in polymer-solvent systems was undertaken for the purpose of exploring the extent to which reliance may be placed on these theoretical relations from a quantitative point of view.

FIGURE 2. Purpose of the paper as stated by the author of the original paper in the introduction.

“This phenomenon is quite different from phenomenon which we have encountered in binary mixtures of small, molecules of equal size. The diagrams differ in their symmetry and therefore in the location of the critical temperature vs volume fraction. Whereas, in polymer solvent mixtures the critical temperature is observed in very small volume fractions of the polymer, in binary mixtures of small molecules it is apparent around a volume fraction of 0.5

FIGURE 3. Addition to the introduction section to the paper

2. Experiment: We reduced the information regarding the synthesis of the polymers used in Flory's study, since this information was not essential to the understanding of the experiments themselves. However, we maintained the description of the apparatus used for identifying the transition temperatures.

3. Results: We omitted observations of phase equilibria in three component mixtures, whose theoretical analysis was not part of the course, but maintained the original results related to the two component mixtures.

4. Discussion: The original paper simply wrote down the final expressions derived from the theory of polymers in solvents; we did more than that but less than a full derivation of this expression. For example: the entropy of polymers dissolved in solvent was mapped onto the entropy of binary mixtures of equal sized particles as show in the figure below:

*In order to understand the shape of the phase diagrams of polymers in solvent, we will examine those using **similar tools to those we used for regular binary mixtures** ...*
The change in entropy of the mixing process in a regular binary mixture is given by $\Delta S_{mix} = -k_B M [c \ln c + (1-c) \ln(1-c)]$
*When dealing with mixtures of polymers of length N in a solvent, **one can derive the change in entropy to be:***

$$\Delta S_{mix} = -k_B M \left[\frac{c}{N} \ln c + (1-c) \ln(1-c) \right]$$
The division by N represents the reduction of the number of possible configurations as a result from the connectivity of the monomers in the polymers which prevents them from occupying lattice sites randomly

FIGURE 4. Exposition of theoretical analysis in the adapted text.

The expression for the entropy of polymers in a solvent was not presented via a procedure for counting the microstates of the system as derived in a common textbook⁸. Rather, the expression for the entropy was introduced as an analogue of the original expression for the entropy of a binary mixture. This way, the dissimilarity between the expressions related to the division by N of the first component of the expression was emphasized.

DISCUSSION

One of the concerns regarding the adaptation process is that must maintain the purpose and meaning of the original paper. We therefore present here some preliminary evidence concerning the students' perception of the purpose of the paper. However, in this short paper we do not provide information regarding the utility of the APL in teaching the concepts of the specific scientific topic (our case - the thermodynamics of polymer physics) and do not discuss the paper's contribution to students' scientific literacy. We plan to investigate these in the future.

The APL article was given to the students two weeks before the lesson in which the paper was discussed. The students were asked to explain in their own words: *What was the purpose of the research presented in the paper?* Students first answered the question individually and their answers were collected. A subsequent classroom discussion was video recorded. In accord with the purpose stated in Shultz and Flory's paper (see figure 2), we expected the students to say that the objective of the paper was to examine the predictions of the quantitative theory of polymer-solvent mixtures.

Indeed, most students identified the purpose of the study as stated in the original paper. For example, Karen¹⁰ wrote: *"The purpose of the research presented in the paper is to examine the compatibility between the theory of polymer mixtures and the experimental measurements – as to the prediction of the critical composition in which the critical temperature is observed, and the value of the critical temperature itself"*.

However, it seems that the mapping of the more general theory of polymer solutions to the theoretical analysis of binary mixtures of particles with identical sizes directed a few students to interpret the purpose of the paper and its results as refuting (as opposed to generalizing) the basic theory of two molecules with equal size: For example, Danny wrote: *"The purpose of the experiment was to show that when the length of the polymer is large then the calculation we used so far does not provide correct predication since the entropy of a long polymer differs from the entropy we calculated so far, since we assumed that the constraint of the motion of the monomers by other monomers is negligible. But in a long polymer this constraint cannot be neglected"*.

Overall, 3 out of 10 students submitted statements similar to Danny's while 7 out of 10 students provided statements that were aligned better with the original stated purpose of the paper (similar to Karen's). We conclude that we should have taken more care in explicating the role of the research paper in the context of the scientific development in the field;

However, although seemingly incorrect, Danny's answer may also be interpreted as reflecting a sophisticated perspective for the purpose of the paper: he may be explaining how the theory of binary mixtures is *extended* to explain the phase behavior of polymers in solvents. According to this perspective the theory for polymers is *more general* and reduces to the simple case of molecules with identical sizes when $N=1$.

To conclude, the design guidelines we introduced enabled most students to correctly identify the main message and purpose of the *original* paper after reading the *adapted* paper. Further investigation of the reading comprehension of the APL by the students is a work in progress.

REFERENCES

- ¹ See for example: J.K. Lee, and W.E Clark, "High School Social Studies Students' Uses of Online Historical Documents Related to the Cuban Missile Crisis", *Journal of interactive online learning*. 1(2) 1-15. (2003)
- ² A. Yarden, G. Brill, and H. *Journal of Biological Education*, 35(4), 190–195. (2001)
- ³ Herscovitz , O, Kaberman ,Z Saar, Liora and Dori, Y,J "The Relationship Between Metacognition and the Ability to Pose Questions in Chemical Education". In *Metacognition in Science Education: Trends in Current Research*, A. Zohar and Y.J. Dori (eds.), Springer Science,Business Media B.V. (2012)
- ⁴ N. Stelnicki, J. Braga, G.de Vries and S. P Norris *Alberta Science Education Journal* 41, 1 (2011)
- ⁵ D.E. Kanter, *Science Education*, 94(3), 525-551.(2010)
- ⁶ G. Brill, H. Falk, and A. Yarden. *International Journal of Science Education* 26, 4: 497–512 (2004)
- ⁷ E. Langbeheim, S. Livne, S.A. Safran, and E. Yerushalmi, *Am. J. Phys.*80, 51–60. (2012)
- ⁸ K. A. Dill and S. Bromberg, *Molecular Driving Forces: Statistical Thermodynamics in Chemistry and Biology* (Taylor and Francis, New York, 2003).
- ⁹ At very low temperatures, the interactions dominate and the system is phase separated for all compositions. As the temperature is increased, the mixing entropy must be considered. For a system with very little polymer ($c \ll 1$), the addition of additional polymer molecules increases the entropic contribution to the free energy (per monomer) relatively little since it is equal to $k_B T \log[c]/N$. This is larger than the additional attractive interaction energy only at extremely small values of c , due to the factor of $1/N$. Thus, the mixed state is stabilized by the entropy at finite temperatures only in a very small region of concentrations near $c \approx 0$. On the other hand, the addition of a small amount of solvent to a system which is mostly polymer ($c \approx 1$) increases the mixing entropy contribution to the free energy (per solvent molecule) by a relatively larger amount equal to $k_B T \log[1-c]$. This stabilizes the mixed state over a much larger range of monomer volume fractions compared with the case in which polymer is added to a system which is mostly solvent ($c \approx 0$) and is the origin of the observed asymmetry.

¹⁰ All names are pseudonyms