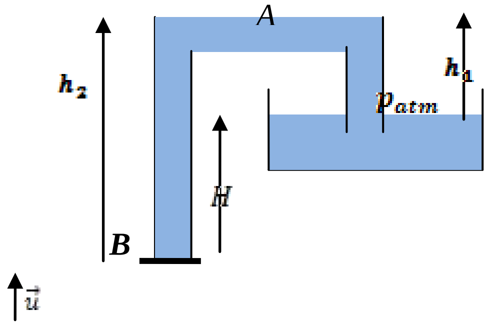
The siphon: a staging focused on a systemic analysis

Laurence Viennot, *laurence.viennot@univ-paris-diderot.fr*
Gorazd Planinsic, *gorazd.planinsic@fmf.uni-lj.si*

The siphon is commonly used in daily life, and it is easy to operate a siphoning device with students. The explanation, however, is far from obvious. Several papers (see for instance Potter & Barnes 1971) recall how to analyse the static situation, i.e. when the end of the tube outside the tank is not yet opened (fig 1).

***Static situation for a siphon** (axis oriented upward)* **:**



In the liquid, the following relationships hold:

$$p_{atm} - p_A = \rho g h_1$$
and
$$p_B - p_A = \rho g h_2$$

therefore :
$$p_B - p_{atm} = \rho g H$$

with $H = h_2 - h_1$

If $H>0$ then $p_B - p_{atm} > 0$

When the end B is open, the tank empties :

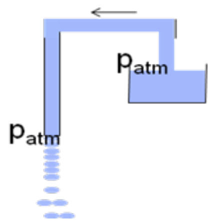


Figure 1. In a static situation, the pressure exerted on the object closing the lower end of the tube is larger than the atmospheric pressure.

From this static analysis, it is not difficult to predict what will happen after this end is opened, and then to yield a first level of explanation. One may also remark that the atmospheric pressure seems not to play any role in this situation. Indeed, in the analysis outlined in Figure 1, it is possible to replace atmospheric pressure by any external pressure, and the conclusion is still that, at the lower end of the tube, the pressure inside the liquid is larger than the external pressure.

Some difficulties occur when one tries to figure out what happens if difference in altitude between the highest part of the tube and the free surface of the fluid (with density ρ) exceeds the difference in height (Δh_{atm}) that corresponds to the atmospheric pressure (p_{atm}). What would happen if the tube initially full of water reached more than 10m above the free surface of the fluid, and if the other end was opened at a level lower than this surface? Would the siphon work? This question ultimately poses that of the role of the atmosphere, and might lead to another question:

would a siphon work on the moon? In the absence of atmosphere, would the cohesive forces in the liquid suffice to ensure the siphoning of the fluid? For more details on these questions, see Potter &Barnes (1971).

Another series of question concerns the dynamics of the flow, once the siphoning is started (see Ganci & Yegorenkov 2008).

Theses questions may seem too complicated for a first approach of the phenomenon, and be provisionally left aside for beginners in Physics. For all that, we might avoid contenting ourselves with oversimplified explanations. One would be to analyse the setting as if it were a mere pulley. A video ("pulley siphon"*) can be used to invalidate this idea. This paper centres on another type of explanation, that stresses the systemic analysis (Viennot 2009). To this end, it is useful to have in mind the main features of a common way of reasoning about systems: linear causal reasoning.

Linear causal reasoning

Linear causal reasoning is of particular interest in that it is in stark contrast with some models commonly used in physics, and particularly in elementary physics.

Consider a system comprising several objects, say two springs suspended end to end from a stand and extended by an experimenter (fig. 2), or a series circuit with two resistors and a battery, or two cylindrical vessels filled with gas and separated by a piston. Such systems can be described with several variables that are constrained by simple relationships. Thus, the forces exerted by the two springs on each other are equal to that exerted by the experimenter on the lower end of the lower spring. This relationship implies a situation of mechanical equilibrium at each point in time, the same time argument being ascribed to each separate value of the concerned quantities. In other words, all the parts of the combined system are assumed to "know" all the other parts *instantaneously*, during the – *quasi-static* – evolution of this system. Thus, if the lower end is pulled by an experimenter, the relationship mentioned above is assumed to hold at any one time. This is far from obvious. In the case of an earthquake, for instance, this model would not be appropriate to analyse the changes affecting two contiguous parts of a continent. It would have to be changed for a *propagative* model. In passing, we note that it is more common, up to college level, to discuss the relevance of a quasi-static model in thermodynamics than in mechanics.

The simultaneous evolution of all the parts of a system is far from intuitively clear. Common ways to deny such a strange hypothesis take the form of the following prototypical comment (Fauconnet 1981: 111; Viennot 2001: 98) "The first spring will extend and then, after a certain time, the second will also extend". Instead of simultaneous changes in several variables permanently constrained by the same relationships, such a comment is termed as a story. Simple events (φ_n), most often specified through only one variable, are envisaged with binary cause-effect links: $\varphi_1 \rightarrow \varphi_2 \rightarrow \varphi_3 \rightarrow (\ldots) \rightarrow \varphi_n$. (Rozier & Viennnot 1991, Viennot 2001: chap. 5). The arrow used in the preceding symbolic form is often worded using the adverb “then”. This is an intermediate term between the expression of a logical link (“therefore”) and a temporal succession (“later”). We can find the same type of ambiguous term in many other languages as well; for instance “alors” in French or “entonçes” in Spanish. More or less secretly, common explanations are steeped in time.

Figure 2 outlines the term-to-term opposition that exists between the linear common reasoning and a quasi-static, or quasi-stationary analysis of a systemic change. Not only do these two different approaches differ in their wording, the corresponding solutions for a given question are also different. For instance, the lengthening of the upper spring for a given total extension can be found too large by a student who proceeds as follows: first consider the extension of the lower spring as equal to the displacement of the lower point, then calculate the corresponding force, then apply this force to the upper spring, then calculate the corresponding extension.

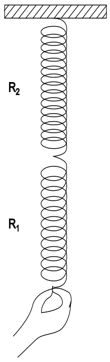
In quasi-static physics	An example	**Linear causal stories**
- several variables - simultaneously changing - constrained by permanent relationships		- simple phenomena (one variable each) - seen as successive (hence as) - temporary
$\mathbf{F}_{ext}$ (t) = $\mathbf{T}_1$ (same t) = $\mathbf{T}_2$ (same t) Δl_T (t) = Δl_1 (same t) + Δl_2 (same t) $\mathbf{F}_{ext}$: Force exerted by an experimenter on the lower end ; $\mathbf{T}_1$, $\mathbf{T}_2$: tensions of each spring; Δl_1, Δl_2 : extensions of each spring, Δl_T total extension.		*A symptomatic comment:* “The first spring will extend then, after a certain amount of time, the second will also extend.”

Figure 2. The main features of linear causal reasoning, as opposed to those of a quasi-static analysis.

Expert explanations that echo linear causal reasoning

As already pinpointed by Rozier and Viennot (1991, see also Viennot 2001: chap. 5), some expert explanations seem to be framed by linear causal reasoning, a tendency that can be particularly perpetrated by authors of science popularization documents. The following example, in line with the theme of this paper, is about a simple experiment.

Figure 3 shows a siphon and an excerpt of an explanation again given by Marie Curie (Chavannes 1907: 62). *The water in the long branch of the siphon flows out. A vacuum is created, and the atmospheric pressure pushes the water of the tank up the short branch.*

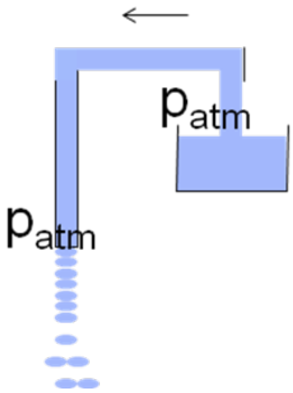


Figure 3. A siphoning process.

Using the preceding schematic presentation, we might paraphrase this explanation as follows:

φ_1 (left end of the tube, on fig. 3): *The water in the long branch of the siphon flows out* → φ_2 (somewhere in the tube) *A vacuum is created* → φ_3 (right end of the tube on fig. 3) *the atmospheric pressure pushes the water of the tank up the small branch.*

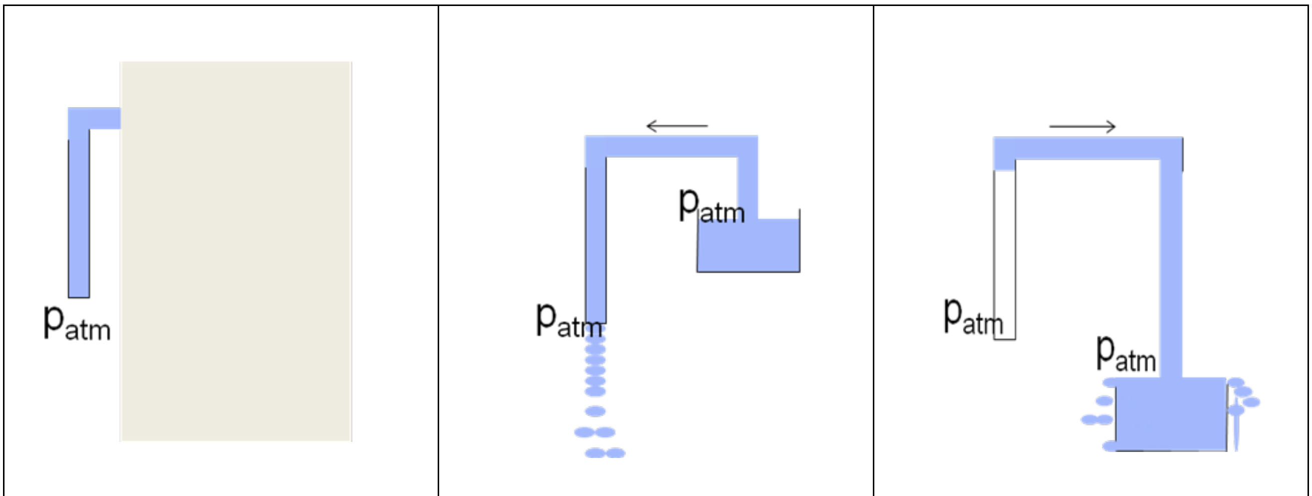
Simple events are envisaged successively, if only temporarily (for instance: “the vacuum”), as though in chronological succession. In particular, this would seem to suggest that it is possible to analyse what happens at one end of the system independently of what happens at the other.

There is one clear problem: The role of the atmosphere is called on for the last link of the explanation, which concerns one end, but there is atmospheric pressure at the other end as well.

The adjectives “long” and “short” constitute a clue which discretely points towards the crucial role of a difference. Most probably, this clue is not sufficient for learners who do not already know how to analyse this system. It might well be thought, for instance, that the water flows out of “the long pipe” simply because its lower end is open. The resonance between this explanation and linear causal reasoning, clearly, may induce improper interpretations.

Stressing links … and the decisive role of some differences

Analysing the possible risks attached to a simple experiment is a stimulation to choose its main teaching goal more explicitly. Thus, still using the same device, it may be decided to stress the systemic aspect of a siphon. To this end, the students can be first presented with a system analogous to that shown in Figure 3 but with a mask hiding the right side (fig. 4a); the student could be asked to predict: What would happen if the lower end of the left branch, initially blocked, were freed? Once performed, the experiment would confirm what is commonly expected: the water flows out of the left branch. When the mask is taken off (fig. 4b), the students can see that the vessel empties, which is the usual goal of a siphoning process. But the experiment could also be performed for a different outcome. Behind the mask, and with exactly the same visible part on the left, it is possible to place the tank of water such that its free surface is *lower* than the end of the left branch (fig.4c). Then, when the left end of the tube is opened, the water does not flow out. Instead, the water rises up the tube and refills the tank.



a	b	c
What will happen when the left branch is opened at its lower end? (Right part of the system: hidden)	A case currently explained by experts (e.g. Marie Curie: Chavannes 1907)	With the same left branch, a different outcome is observed

Figure 4. Without considering both sides of a siphon, the outcome of the experiment cannot be predicted.

This is a striking illustration that, without seeing *both* ends of the system, it is impossible to predict what the water will do. This is the most important thing to be understood concerning a siphon. Beyond that, with a modest setting, and with an audience that is still at a low level of competence, it is possible to stress a crucial aspect of physical phenomena: the world runs on *differences* (Boohan and Ogborn 1997).

Final remarks

With this example, it can be seen that, with the same basic setting, we can actually bring to bear very different teaching strategies. In terms of learning outcomes, it is reasonable to think that, correspondingly, significant differences will be observed.

Keeping in mind the relevance of a systemic approach, the staging of other experiments can be re-orientated accordingly. This is illustrated in Appendix with the case of a love-meter.

This kind of approach comes down to stressing the consistency of physics and the power of its theoretical foundations – here, the idea that the world runs on differences.

* "Pulley siphon" video: Communication with Gorazd Planinsic and Josip Slisko, to be sent for publication in Physics Education.

Appendix

A "love-meter" is shown in Figure 5. Warming up the lower part with the hands results in a nice fountain effect, with the liquid partly filling in the higher part whereas its level decreases in the lower part. The usual explanation is that, warming up the gas in the lower part also increases the pressure there, which pushes the liquid up the tube joining the bottom of the lower part to the bottom of the higher part. Here, we recognize a linear causal reasoning.

Figure 5. A "love-meter" with the classical staging.

In order to better stress the target idea, we could formulate the explanation more precisely, changing "the pressure increases in the lower part" for "the *difference* of pressure between the *two* parts is increased", a way to take into account both parts of the system. With such a target in mind, it would become natural to complete the classical demonstration of the love-meter experiment with the following variation (fig. 6b): cooling down the higher bulb, for instance with cold water. The outcome is of course the same as with the usual version, which constitutes a rather striking effect.

	
Starting with the classical use of a love-meter …	…then getting the same effect by cooling down the upper bulb with cold water

Figure 6. A staging focused on a systemic analysis

References

Boohan, R. & Ogborn, J. 1997. Differences, energy and change : a simple approach through pictures, *New ways of teaching physics* - Proceedings of the GIREP International Conference 1996 in Ljubliana, S. Oblack, M.Hribar, K. Luchner, M. Munih, Board of Education Slovenia.

Curie, M. 1907-2003. Leçons de Marie Curie, recueillies par Isabelle Chavannes en 1907. *Physique élémentaire pour les enfants de nos amis*. Dir. B. Leclercq, Paris : EDP Sciences, 2003

Ganci, S.& Yegorenkov, V. 2008. Historical and pedagogical aspects of a humble instrument, *European Journal of Physics*, 29, 421–430

Gianino C 2007 A strange fountain *Physics Education* 42, 488

Potter, A. &Barnes, F.H. 1971. *Physics Education*. 6, 362-366

preconceptions in science. *European Journal of Science Education*, 8 (2), 155-171.

Rozier S., Viennot L. 1991, Students' reasoning in thermodynamics, *International Journal of Science Education*, Vol 13 n°2, pp. 159-170.

Santamaria, C. 2007. *La physique tout simplement –Ne vous noyez pas dans un verre d'eau*, Paris : Ellipses, p.28

Viennot, L. 2001. *Reasoning in physics*. The part of common sense, Bruxelles: Kluwer.

Viennot 2009. Physics by inquiry: beyond rituals and echo-explanations, To be published In *New Trends in Science and Technology Education*, G. Santoro (Ed.): "New Trends in Science and Technology Education" Conference, Modena, CLUEB, Bologna.