Monitoring the wave phenomena leading process through Bayesian updating activities

Students show a marked deficit in meta-cognitive control [1-4].

The lack in the awareness about one own process of thoughts and learning is also the cause of a often falling in the overestimation of their own degree of comprehension, believing they know more than what they are effectively able to recall under testing [5-8].

Students may vary approach according to their own personal beliefs about science, result- ing even in different, correlated, scholastic performance[9-12].

IT IS ESSENTIAL TO UPDATE PHYSICS COURSES AND TEACHING METHODS, TO MEET THE NEEDS OF THE SCIENTIFIC REALITY, GUIDING STUDENTS TOWARDS THE CORRECT COMPREHENSION AND APPLICATION OF THE HYPOTHETICO-DEDUCTIVE PROCESS IN PROBLEM SOLVING AND IN THE DEVELOPMENT AND UNDERSTANDING OF LAB ACTIVITIES.

Exploringing the possibility of introducing activities denominated **"Bayesian updating"** in Italian High school for scientific studies, we tired to elaborate and implement an **on line educational tool** regarding the theory of probability and wave phenomena using the "DESMOS" platform [QR code] to achieve these important skills in students.

IS IT POSSIBLE TO PROMOTE THE DEVELOPMENT OF METACOGNITIVE SKILLS IN PHYSICS' HIGH SCHOOL STUDENTS?

OUR WORK IS GREATLY INSPIRED BY WARREN'S RESEARCH [13, 14 - QR CODES] IN WHICH HE TESTED THE IMPLEMENTATION OF BAYESIAN UPDATING ACTIVITIES TO ALGEBRA-BASED AND CALCULUS-BASED INTRODUCTORY PHYSICS COURSES.

In his papers he designed curricular material to introduce students to the hypothetic-deductive process using Bayes' theorem (**the equation in the circle**) to numerically express and update through a mathematical instrument the level of confidence obtained in a certain hypothesis.

A BAYESIAN UPDATING ACTIVITY IS STRUCTURED LIKE SO:

1. An hypothesis needs to be tested
2. An initial subjective level of confidence *Ci* to put in said hypothesis is established
3. an empirical/experimental (direct) or theoretical (indirect) evaluation is designed and then executed
4. given the result of the evaluation, the Bayes factor R is established through a partially subjective choice following Jeffreys's scale's directions
5. an updated level of final confidence *Cf* is calculated through Bayes' theorem

$$C_f = \frac{C_i \cdot R}{C_i \cdot R + 1 - C_i}$$

BAYES' THEOREM AND FALSE NEGATIVES

Bayes' theorem is often presented to high-school students as an abstract mathematical tool without a well-defined origin, useful only in ideal situations.

With the purpose of opposing this practice we spent some time discussing and obtaining through calculus Bayes' theorem's general expression. For a deep insight in the theorem's meaning We specifically designed an exercise regarding current actual events. In this way we also showed the theorem's inferential power in a realistic context, that is what we would then do in Physics.

So, we decided to talk about Covid-19 and the related diagnostic tools: we asked students what might be the probability of being infected even though having received a negative result with the swab test (false negative), that was a really problem during the pandemic spread-out.

PROBLEM SOLVING THROUGH UPDATING ACTIVITIES

With the intent of developing problem solving skills we took exercises from a book and re-elaborated them to include Bayesian updating and thought experiment, showing the participants how they can approach future problems being able to self-evaluate their own work and without having to rely on the books' solutions or the teacher's authority. From now on we will analyze a very common exercise about sound waves and the condition of destructive interference. The first step is to ask the students what is their initial level of confidence about being able to solve the suggested exercise. Then the participants are required to actually solve the problem and elaborate a thought experiment to test their so- lution method. The evaluation may consist in a change of parameters or context, with the intent of tracing themselves back to a known situation in which they are confident of what to expect.

TO EFFECTIVELY IMPLEMENT BAYESIAN UPDATING ACTIVITIES TO PHYSICS CURRICULUM IS NECESSARY TO DESIGN SPECIFIC ACTIVITIES AND REELABORATE PROBLEMS AND EXERCISES AS TO INCLUDE THE BASICS STEPS OF THE PROCESS. HERE WE PRESENT THE MAIN CONTENT ASPECTS FROM OUR PROJECT SO THEY MAY SERVE AS EXAMPLES AND THEY SHOW A WAY FOR DEVELOPING A BAYESIAN UPDATING ACTIVITY IN EVERY PHYSICS CLASS AND FOR ANY CURRICULUM STUDY.

LAB ACTIVITIES AND EVOLUTION OF CONFIDENCE

With the same approach we also implemented Bayesian updating to Lab activities to develop basic applied physics' skills. Due to epidemic-related restrictions it was not possible to actually set up a real laboratory, nonetheless the website "The Physics Classroom" [QR code] offers a realistic simulation of Thomas Young's two slit interference experiment with changeable parameters that also requires actual measuring skills. We hypothesized each student bought a red laser from a seller who claims its wavelength is $\lambda = 700nm$ and asked the students to test this hypothesis through Young's experiment. The simulation changes its unknown parameters at each restart so every participant has a laser of different wavelength causing some to receive a confirmation and others a confutation. The assignment was to complete some given tables that guided them to execute the experience multiple times changing parameters and conditions, updating their confidence after each time. Since the simulation lets them also change colors of the laser, we then asked the students to put to the test not the hypothesis itself, but the evaluation method. We discussed what they expect it would happen with a change of color if the method was correct and then, actually made them try to manipulate the simulation to receive a confirmation or confutation.

ESSENTIAL BIBILOGRAPHY:

[1] M. Hammer, Cogn. Instruct. 12(2), 151 (1994).
[2] D.B. May and E. Etkina, Am. J. of Phys. 70(12), 1249 (2002).
[3] B.K. Hofe and P.R. Pintrich, Rev. Educ. Res. 67, 88 (1997).
[4] D. Hammer, Phys. Teach. 27, 664 (1989).
[5] R. Azevedo, R. Behagh, M. Duffy, J. Harley and G. Trevors, in Theoretical foundations of student-centered learning envi- ronments, New York, 2012, edited by D. Jonassen and S. Land (Routledge, New York, 2012), p. 171.
[6] P. Winne and R. Azevedo, in The Cambridge Handbook of the Learning Sciences, Cambridge, 2014, edited by R. Sawyer 203. (Cambridge University Press, Cambridge, 201), p. 171.
[7] A. Elby, Am. J. Phys., Phys. Educ. Suppl. 69, S54 (2001).
[8] R. Mota, The Physics Educator 1(01), 1950002 (2019).
[9] C. Sin, Sc. Ed. 98(2), 342 (2014).
[10] A. diSessa, Cog. Instruct. 10(2/3), 105 (1993).
[11] M. Wells and D. Hestenes, Am. J. of Phys. 63, 606 (1995).
[12] T. Erickson, Teach. Stat. 39, 30 (2017).
[13] A.R. Warren, Am. J. of Phys. 86(5), 368 (2018).
[14] A.R. Warren, Phys. Rev. Phys. Ed. Res. Phys. 16(1), 010101 (2020).

RESEARCH METHOD

Our research lasted 8 weeks and took place in an Italian high-school involving two class of the fourth year (17-18 years old students), one from the (traditional) scientific course (18 students), the other from the applied sciences one (25 students), both having the same mathematics and physics' curriculum. Being in the middle of the Covid- 19 epidemic with the related restrictions and lockdown, the entire activity has been designed to be held via online platforms; communicating with the students through virtual meeting while discussing an interactive slideshow devel- oped through the "DESMOS" website. The Bayesian updating is an extremely versatile tool that can be adapted to any physics-related subject and in the course of this research we opted for wave phenomena as it was the subject planned by the teachers to occur in that period.

THE ON LINE INTERACTIVE ACTIVITY HAS BEEN SPLIT INTO 3 DIFFERENT SECTIONS:

1. First an introduction to the theory of probability to address all the mathematical tools necessary to proceed in the activity. The main focus of this section is the Bayes' theorem and its possible applications.
2. Second an in-depth analysis of the concept of thought experiment and indirect evaluation applied to wave- related exercises utilizing the Bayesian
3. Third an exploration of the idea of direct evaluation, with the use of Bayesian updating , discussing the structure of an experiment and the concept of statistic and systematic errors and how they can affect the level of confirmation/ confutation.

ASSESSMENT

At the end of the activity we made the students submit a survey we purposefully made to evaluate the whole project itself and, moreover, the meta-cognitive impact obtained. The most significant result is that a great number of participants recognize the importance of self-reliability and consider Bayesian updating activities to be effective as a self-evaluation tool.

DISCUSSION AND CONCLUSIONS

There is an incredible adaptability of this kind of activities, applicable to every topic of the physics' curriculum. The nested interplay with the use of the Bayes' theorem is an inter-disciplinary key that confirms the nature of this kind of approach. Bayesian updating activity helps develop basic concept fundamental for the comprehension of every scien- tific topic, not just in physics, suggesting the possibility of implementing this tool to every subject, creating interrela-tions and promoting students' epistemological development in the course of the whole academic year. All said above suggests the need for further explorations and future works about this new approach we adopted, both in high school and university.

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