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The computer supported environment LabNbook has been proposed to high school and university teachers to support the production of experimental reports or lab notebooks by students. Our focus is on activities where students have to design experiments including a formalisation part through the writing of the experimental protocol. LabNbook provides a protocol editor, Copex, to support students in this formalisation of their experiment. We investigate the pedagogical strategies developed by teachers to make students write protocols using the Copex tool. Forty-nine activities from twenty-one teaching units are analysed. While some teaching units do not spend much on the writing of the protocol, various creative strategies are proposed by the teachers with Copex. An insight on the use of Copex by students shows that the spontaneous use of Copex by the students for writing a protocol is encouraged by the value teachers give to the writing of the protocol and to the use of Copex, in previous activities. Two teachers' interviews show that the structuring power of the writing of the protocol supported by Copex, is used in particular to make students structure their work and thus better understand and connect, the strategy and the details of the experiment.

Keywords: Computer Supported Learning Environments, Laboratory Work in Science, Learning by Design

INTRODUCTION

Literature shows added values and benefits brought by active learning based education (e.g. inquiry learning, problem- or project-based learning (PBL), in terms of conceptual learning (Freeman et al., 2014). Among the possible activities associated to active learning, we are specifically interested in the design of experiments by students that helps them acquire new scientific skills (Etkina, Karelina & Ruibal-Villasenor, 2010).

LabNbook (labnbook.fr) is an online learning environment, which has been initially designed for researchers, to study the design of experiments by the students. LabNbook supports students (and teachers) who are committed to active learning based education and need to write either a lab notebook or a scientific report (e.g. inquiry learning, problem- or project-based learning (PBL), experimental process). For the means of designing experiments, LabNbook includes a protocol editor, named Copex, an original tool to support the writing of structured experimental protocols. This tool is based on one main hypothesis, valid for both high school and university learning: the design of an experiment is at the centre of the experimental process and can be related to each step of this process. This design task is complex and demanding and requires guidance in order to make it feasible by the students. This is supported by several researches in science education (Etkina et al., 2010; Girault, d'Ham, Ney, Sanchez & Wajeman, 2012; Girault & d'Ham, 2014; Arnold, Kremer & Mayer, 2014; van Riesen, Gijlers, Anjewierden & de Jong, 2018; Xenofontos, Zacharias & Hovardas, 2018). Most of these studies do not pay a particular attention to the experimental protocol which describes the experiment and belongs to the experimental process.

The experimental protocol

In our research, we put emphasis on the experimental protocol, in the belief it can play an important role for scientific learning through the design of an experiment. The protocol is a true scientific object that fulfils several functions in the experimental process. Despite an experimental protocol is compulsory in an experimental process, scientific publications seldom deal with it on epistemological issues. Discussions are mostly limited to repeatability and reproducibility questions, and to communicability for assessment by experts (see for instance Dean & Voss, 1999; Selwyn, 1996). This corresponds to an underlying practice: a protocol is a memory of what has been done during the experiment and it describes how the collected data were produced. A protocol carries thus essential information for data analysis and interpretation and for subsequent discussions. In books about the design of scientific experiments (Dean & Voss, 1999; Selwyn, 1996), the protocol is mentioned as a writing part that describes the procedure of an experiment (actions to carry out the experiment) and have to include objectives, information about material and apparatus and the data processing can have to be described as well. Selwyn underlines the necessity of writing a protocol before carrying out the experiment because "experiments that are designed on the fly are rarely successful". Thus the writing of a clear and structured protocol obliges to think, formalize and make clear what one is willing to do; it has to be assessed and improved. The protocol contains theoretical terms and is directed by concepts. The designer has thus to build links between the world of ideas and the world of facts (Tiberghien, Psillos & Koumaras, 1995).

What is the place and role of the experimental protocol in scientific education? For instance, the French upper secondary school curricula (ending 2020) often mention "run a protocol, sometimes "design and run a protocol" and once “propose a critical analysis of a protocol”. Following Chevallard’s framework (1985) to describe knowledge in an ecological context, the protocol can be considered as a para-scientific object: it is a scientific tool that a student must be able to use, but it is not a subject to be taught in itself and it is never defined nor described. In a previous study (Girault et al., 2012), laboratory manuals were analysed at high school level and at the first years of university. It showed that the protocols given to students in cookbook labs have various forms and do not resemble protocols as scientists would write them. The students may thus have difficulties to build a clear image of a protocol.

The protocol editor Copex

After performing several experiments where students design an experiment and write the protocol, we have built a model of a protocol (Bonnat, Marzin-Janvier, Girault & d’Ham, 2019). The model is simple and flexible in order to make it usable for a variety of protocols and suitable at upper secondary school level and for university students. This model was implemented in a protocol editor Copex. A high gain of Copex is to foster the writing of short sentences that are easy to understand, to include drawings, comments and tables and organise the procedure in a hierarchical way. The Copex model is composed of four introductory rubrics followed by the procedure. These rubrics are: Experiment objectives or research question, Experiment hypotheses or expected results, Experiment principle, List of material. The procedure is the description of the experimental actions to be carried out when running the experiment. The procedure is organised in steps, sub-steps and actions. Thus, Copex model supports a structured vision of the experiment that can be built by articulating a global view through the rubrics and the procedure main steps, with the details through sub-steps, actions (there is a possibility to add actions comments). Furthermore, looking ahead for what the experiment should produce (expected results) and connecting it with the hypotheses, requires reflecting on the relevance of the experiment and should foster problem solving.

Copex is available on the LabNbook platform (d'Ham, Wajeman, Girault & Marzin-Janvier, 2019), where students produce scientific reports collaboratively. Since LabNbook does not include content and do not address any pedagogy, the teachers have freedom to design the activity they wish for their students with the pedagogy they want. The teacher configures a template of the students' working space, named “mission”. The students work in collaboration in their own shared working space, named “report”: they write down their report by using four LabNbook editors, including the original protocol editor Copex. Copex can be fine-tuned by the teacher to structure the activity of experimental design at different levels. The teacher can include in the students' workspace a predefined Copex document, i.e. a protocol template which can be totally or partially filled, or empty. She/he can add instructions in the mission to assign a task to the students and to guide them. However, using a protocol editor is not a usual scientific or a teaching practice. Therefore teachers and students may use the LabNbook text editor for writing protocols instead of Copex editor.

Research questions

From 2017, LabNbook has been used by about 140 teachers. In this paper, we address the question of how the protocol editor Copex is used by teachers and students during experimental design activities to make students work on the experimental protocol. There could be a variety of uses of Copex by the teachers since they can structure the activity of experimental design at different levels. We specify two research questions (RQ) through the analysis of teachers' productions and of students' activity:

- RQ1: Which activities regarding the protocol do teachers propose to their students using the Copex protocol editor? What guidance do they implement within LabNbook to help their students in these tasks? Which pedagogical roles/values do teachers assign to these tasks?
- RQ2: When students have to design an experiment, do they spontaneously use Copex to write their experimental protocol? In which teaching circumstances?

DATA AND METHOD

Around 250 pedagogical activities have been created with LabNbook and used for teaching from September 2017 to January 2019, both at high school level (students aged 15 to 18) and at University level (age 19 to 23). The pedagogical activities are diverse, some teachers use LabNbook for one activity that lasts between two and four hours, while others use it through one semester for a project-based learning or for a collection of laboratory works during the two consecutive years of our study. Two kinds of data are used in this study: first we collect the template of working spaces, called missions, that have been built by the teachers for their students. Then, for collecting more information about the teaching process and the teacher's intentions, we conducted an interview with two teachers who designed a mission.

Missions

To answer RQ1 we analyse the 25 missions (10 at high school level and 15 at university level), that include predefined Copex documents (*i.e.* protocols given by the teachers in the template), spread over 12 teaching units (set 1). We collect 24 extra missions (set 2, organised in 9 teaching units) that have no predefined Copex document, while a Copex document was added by students in their LabNbook report. This reveals that students are expected to write a protocol. Among these 24 missions, 15 are connected to missions with predefined Copex documents, so they can be part of a guidance strategy.

For the selected missions, we use an analysis grid to analyse the predefined Copex documents (set 1 only) and the instructions within a mission, in order to identify the tasks that are demanded to the students regarding the experimental protocol. We thus seek for

1. the written instructions within the missions that are related to Copex or/and to a protocol.
2. information that is given or that is to be completed by the students within a predefined Copex document (set1), regarding the rubrics (objective, hypotheses, principle, material), and the procedure (steps, actions).

Students

To answer RQ2, we analyse the second set of selected missions (set 2). For each mission, we calculate the ratio of students who use Copex to write a protocol on all the students who work on the same mission.

Teachers' interviews

We choose two teachers who give an important and original place to the protocol within the missions they designed. These teachers do not use the protocol in the same way and they teach in different contexts.

Teacher 1 is an upper secondary school teacher in chemistry and physics for K12 level students (30 per year). He designed three missions for his own use, following his own will to improve his teaching.

Teacher 2 is teaching laboratories in electronics in an engineering school (L3 level, 360 students per year), and is part of a team of teachers. There is an institutional will to renew and improve all the laboratories. The interviewed teacher designed two missions belonging to two different teaching units, each one taking place at a different semester of L3. In fact, his students follow each semester other teaching units (labs in physics) using LabNbook.

The two teachers are interviewed in a semi-open mode (Planche et al., 2019), to make them express their motivation and objectives, tell what they did to make their students work with the protocol, what was successful and what has to be modified. We want to figure out the epistemological and pedagogical role they give to the protocol in the laboratory work they designed.

ANALYSIS OF MISSIONS

Guidance through Copex

We analyse the protocols in the predefined Copex documents of the 25 missions of set 1, to identify what kind of information is given by the teachers or is to be completed by the students: objective, hypotheses or expected results, principle, material, procedure (steps and tasks). We also look for instructions related to the production of the experimental protocol(s).

	Number of missions (a total of 25 missions)
Presence of predefined Copex documents with only a title	11
Teachers fill at least one rubric among research questions, hypotheses or expected results, principle	19
Steps and actions are given	7
Only steps are given	9
Only actions are given	0

Table 1. Types of information given by the teachers in predefined Copex documents. There can be more than one predefined Copex document in a mission.

The teachers use several guidance strategies to guide the students in the design of a protocol.

- The minimum of guidance is to give students an empty Copex document in the mission. This way, teachers push the students to use Copex to write a protocol. When creating a new document, giving a title is mandatory, this explains why there is at least a title. This is the case in 11/25 missions.
- Another type of guidance is to give students the context of the procedure that will be written by them. This corresponds to one, two or three rubrics filled with research questions or objectives, hypotheses or expected results and the principle of the experiment. This is the case in the majority of protocols (19/25).
- Regarding the procedure itself, some teachers give steps and actions (7/25) or only the steps (9/25). Our analysis shows that there are no missions (0/25) where the teachers would give the actions and the students would have to organise them by adding the steps.

We seek for instructions (in the mission and/or in the teachers' interviews) to associate the type of guidance with intended pedagogical activities. For this we also take into account the the 15 missions within set 2 (no predefined Copex documents) that have a connection with missions that do include predefined Copex documents.

We highlight several pedagogical activities. Some of them correspond to an activity inside a Copex document, while other activities imply an evolution throughout several Copex documents inside a single mission or through several missions. We are able to relate some activities to a pedagogical scenario that we describe in relation to the activities.

- A procedure (steps and actions) is given and the students have to infer the problem to be solved and the expected results (1/25 mission). The teacher expects students to have an overview of their protocol.
- The teacher gives the principle in the dedicated area and through the steps, and the students have to give the details by writing actions (1/25 mission). This gives the students an opportunity to detail the experiment that will be done, to force them to face the complexity of an experiment.
- A Copex document is given with steps and/or actions in an alphabetic order and students have to organise them (3/25 missions, 3 teaching units).
- Students are expected to write the entire protocols with no visible guidance (3/25 missions, 2 teaching units). These missions only propose an empty Copex document. For two of them, the students are working in a project at master level and probably have a degree of autonomy to write their protocol and get feedback from the teacher.
- Students are expected to write the entire protocols with guidance available in a resource area of the mission (1/25 mission). This is a sheet telling how to write a protocol.
- A Copex document is filled by the teacher and given as an example in a mission. Then, students have to write new protocols based on the given example. Combining the two sets of missions, we can describe different cases:
    - students have to learn from one example in a first mission, there is no predefined Copex document in the next missions of the same teaching unit (1/25 mission);
    - there is a fading throughout one mission with several Copex documents having less and less information (2/25 missions, 2 teaching units); or the fading happens throughout several missions (8/25 missions, 3 teaching units). The guidance is strong at the beginning and gradually fades to end with no scaffolds at all. Details are given in the next part, since the two interviewed teachers practice such fading guidance.

Detailed description of the teaching of the two interviewed teachers

Teacher 1: he designed three missions in LabNbook, all related to a transverse theme, the calibration of measuring tools, with a fading effect in the guidance. In the first mission, the teacher offers students a procedure with only steps that can be converted to actions and then steps and actions need to be ordered. In the two other laboratories, students are given only steps to order and must add the actions and the knowledge has to be transferred to a new experimental situation. According to the teacher, the last situation, which is not guided anymore, is significantly more difficult than the previous ones.

Teacher 2: the students have to write protocols in 15 missions within five teaching units during three consecutive semesters: semester 1 (teaching units T1 and T2), semester 2 (T3 and T4) and semester 3 (T5). Teacher 2 designed two LabNbook missions in teaching units T1 and T3, always with predefined Copex documents.

In T1, Teacher 2 designed four laboratories, but only one with LabNbook. The guidance appears through a sheet to be filled for the three paper-and-pencil labs, and with several predefined Copex documents with a fading effect along the LabNbook mission.

He designed one mission in T3, where several protocols are demanded to the students. The students have to exchange one set of data with another group of students (they give one data set and get one); they have to provide the protocol they designed and used to collect the data, and on the other hand they have to analyse and interpret the data set they receive.

These students experience guided protocol writing in two other teaching units: the guidance in T2 is faded through three missions, with predefined Copex documents only in the two first missions. Students use Copex in the third mission without being told. In the 6 missions of teaching unit T4, no predefined Copex documents are given but the students are reminded of Copex with an instruction giving the exact names of its rubrics.

In the 4 missions of T5, taking place the next year, students have to write protocols too, but nothing is done to remind them of Copex. However, the students continue using Copex.

Spontaneous use of a Copex document

Engineering school students do use Copex when there is no predefined Copex document in a mission (RQ2): when there is guidance almost all students use Copex (112/118 reports (95%) for the last mission of T2; 80/90 (89%) for the 6 missions of T4). The next year, students go on using Copex with no guidance at all (15/31 reports (50%) for the 4 missions of T5).

It can be compared with 4 other teaching units (within set 2) for which students are asked to write a protocol but with nothing to encourage the use of Copex in the mission or in connected missions. Some students do use Copex however. The number of students' reports using Copex spontaneously is between 5 to 20% (2/41 to 33/159). This suggests that students seldom use spontaneously Copex to write a protocol when they have not been taught and encouraged to use it.

TEACHERS'INTERVIEWS: DISCUSSION

Acquiring structures for a better understanding

Despite the different contexts, there are similarities between the two cases. First the two teachers have a common major trigger: they are struck by the fact that students do not understand what they are doing and are always focused on a single task at a time without any idea of where it should lead them. Thus they both want to guide their students into a structuring process that will help them to overcome this difficulty and for this they implement guidance with a fading effect. The work with experimental protocols takes a large part in this structuring process. Both tell to have succeeded and that some students said that they better organise their work and thus better understand what they are doing. Teacher 2 says that most students keep on structuring without being told the next year (Master 1) as is observed from our analysis. As described previously, the students were guided for structuring their work through four teaching units and 11 missions, all along the first year (Licence 3). According to the teacher, it is necessary to keep these guidance effort and stringent requirement for a year.

Teacher 1 comments the exercise he proposes in the first mission: this exercise engages all the students, whatever their achievement level, into a rich and collaborative cognitive activity. Students are asked to organise the procedure: they decide the status of each items, step or action, and discuss their position in the procedure and the meaning of it. They deeply experience the hierarchical nature of the protocol and the teacher does observe it "I almost watch the wheels in their brains rotate". Students are autonomous in conducting the process for the third mission despite a strong increase in the difficulty. The students do build a solving path, they link the global view to the detailed actions, identify the global objective, and they do not lose it anymore. It must be underlined that the procedures designed by both teachers include data processing and sometimes elements for data analysis and interpretation (such as "compare to the theoretical model or value"), and thus covers a large part of the experimental process at stake.

Paper pencil versus numerical tool

However, both teachers express reservations. Teacher 1 says that he was not able to check, and thus that he was not convinced, that his students would be able to transfer this know-how to another type of contents. But he said too that the exercise with the protocol cannot be achieved without Copex, and furthermore, when asking his students to write protocols in paper pencil mode, he is unable to guide and check the writing of the protocol before the students carry out the experiment. Teacher 2 thinks that it is necessary to combine both pencil paper and numerical mode for the writing of the reports. He fears that the use of the numerical support only could drive the students to think that the demanded structure of the report could be related to the numerical tool. Then they may not understand this structure as a general resource for laboratories and could not reuse it.

Role of the protocol

The two teachers do not consider the main role of the protocol in the same way: at high school, students have to build a structured description of what has to be done in order to carry out the experiment. The role of the protocol is mainly the design of the experiment, thus thinking and structuring the experiment ahead. This role, even if teacher 2 does not put emphasis on it, exists for the engineering students who have to write the protocol before the laboratory. Teacher 2 says that he wants them to reflect and organise the experimental work prior to the laboratory. However, the main point for him is that the protocol tells how the data are collected. This is required to interpret the data and to find out what is wrong when there is a problem with the data. This requires a high quality and detailed procedure. He designs one specific mission (in T3) in order to make the students feel this point and deepen their analysis, making them experience how much data processing and interpretation depends on how data are collected. During the laboratory, he initiates a discussion with the students in a feedback loop between the protocol and the experimental curves obtained from the collected data: he makes the students analyse, check and complete their data and correct and complete the protocol. But he thinks that the protocol writing skills of the students remain fragile.

Copex rubrics (objectives, hypotheses …) do not have the same pedagogical and scientific status for the two teachers. Teacher 1 does not value the rubrics, focusing on the procedure part. However, he tells that some students do fill the rubrics very seriously without being asked, include pictures or use the comments fields to include explanations. On the contrary, the engineering students have to fill the rubrics, and teacher 2 puts a high value on the "hypothesis or expected results" rubric. This is consistent with the role of a protocol as a description of the data.

CONCLUSION

Twenty one teachers, or teams of teachers, have designed on LabNbook platform the 49 pedagogical activities analysed in this paper that propose students to work on the experimental protocol. These scientific activities belong to a variety of teaching units that are meant for very different populations of students, from K10 to M1, at technical and general high school, university, engineering school ... In twelve teaching units, the teachers make use of the protocol editor Copex which seems to provide an appropriate medium. For instance, engineering school teachers go on using Copex protocol model to guide their students. However, our results suggest that students seldom use spontaneously Copex to write their protocols when they have not been taught or encouraged to use it.

The teachers express a true creativity in the building of exercises about the experimental protocol with Copex. A number of teachers seem to want their students to learn how to write an experimental protocol. But the role of the protocol in these activities goes far beyond just telling what one has to do to run the experiment, as it is usual in cookbook laboratories. Students have to use the protocol as a tool for data analysis and interpretation and to discuss data quality. The protocol is used to think and organise the experiment ahead: the students have to write the protocol, to re-organise or analyse the procedure… Both interviewed teachers consider the protocol as an indispensable element of the report. They both highlight the structuring potential of the experimental protocol in fostering understanding. They find here a solution to an initial and common behaviour they both underline as highly problematic: students focusing on a single task they perform, hindering any understanding of the experiment and more generally of their doings.

The analysis of the pedagogical activities with the protocol also carries original pedagogical strategies. For instance some teachers scaffold the students' learning of a structured approach by using a fading effect in the guidance of the activity. Asking the students to structure and organise a protocol within Copex is used successfully to foster the students understanding of the experimental process at stake by building a global view of the process and connecting it to the detailed parts.

The new French secondary school curricula (starting 2018 to 2021) better highlight the scientific role and the pedagogical potential of the experimental protocol. A wide variety of exercises are recommended, such as "discuss the influence of the measurement device and of the protocol with reference to the data accuracy", "test the limit of usage of the protocol", "identify steps in a protocol", "understand the importance of reproducibility of sampling protocols", "do a critical analysis of protocols and justify the techniques used", "compare the pro and cons of protocols". The experimental protocol should thus take a more important place in teaching. This, together with the presented results, supports that the experimental protocol as a key element of experimental processes, is worth to be learnt and could be used as a powerful tool for learning experimental science.

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REFERENCES

Arnold, J. C., Kremer, K.,and Mayer, J. (2014). Understanding students' Experiments. What kind of support do they need in inquiry tasks? *International Journal of Science Education*, *36(16)*, 2719-2749.

Bonnat C., Marzin-Janvier P., Girault I. & d'Ham C. (2018). Modélisation didactique pour la conception d'étayages dans un EIAH : exemple d'une activité de conception expérimentale en biologie. *STICEF*, *25(2)*, 31-61

Chevallard, Y. (1885). *La transposition didactique. Du savoir savant au savoir enseigné*. Grenoble, France: La Pensée Sauvage.

Dean, A.M. and Voss D.T. (1999). *Design and analysis of experiments*. New-York, NY: Springer.

Etkina, E., Karelina, A., & Ruibal-Villasenor, M. (2010). Design and reflection help students develop scientific abilities: learning in introductory physics laboratories. *The Journal of the Learning Sciences*, *19*, 54–98.

Freeman, S., Eddy, S.L., McDonough, M., Smith, M.K., Okoroafor, N., Jordt, H., & Wenderoth, M.P. (2014). Active learning increases student performance in science, engineering, and mathematics. PNAS, *111(23)*, 8410-8415.

Girault, d'Ham, C., Ney, M., Sanchez, E., & Wajeman, C. (2012). Characterizing the Experimental Procedure in Science Laboratories: A preliminary step towards students experimental design. *International Journal of Science Education, 34(6)*, 825–854.

Girault, I., & d'Ham, C. (2014). Scaffolding a Complex Task of Experimental Design in Chemistry with a Computer Environment. *Journal of Science Education and Technology*, 23(4), 514–526.

d'Ham, C., Wajeman, C., Girault, I., & Marzin-Janvier, P. (2019). LabNbook, plateforme numérique support des pédagogies actives et collaboratives en sciences expérimentales. *Actes de la 9ème Conférence sur les Environnements Informatiques pour l'Apprentissage Humain*, 49-60.

Planche, M., Girault, I., Mandran, N., Marzin-Janvier, P., d'Ham, C., & Wajeman, C. (2019). Contribution de différents outils de mesure à l'évaluation des usages d'une plateforme numérique par un processus longitudinal : Cas du travail à distance. *Actes de la 9ème Conférence sur les Environnements Informatiques pour l'Apprentissage Humain*, 139-144.

van Riesen, S., Gijlers, H., Anjewierden, A. & de Jong, T. (2018). Supporting learners' experiment design. *Education Technology Research and Development*, *66*, 475–491.

Selwyn, M.R. (1996). *Principles of Experimental Design for the Life Sciences*. USA: CRC Press.

Tiberghien, A., Psillos, D. & Koumaras, P. (1995). Physics Instruction from epistemological and didactical bases. *Instructional Science*, *22*, 423-444.

Xenofontos, N. & Zacharia, Z. & Hovardas, T. (2018). How Much Guidance Students Need When Designing Experiments. a Computer-Supported Inquiry Learning Environment. *International Journal of Learning and Teaching, 4,* 20-24.