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# Contribute to Open Science with Research-based Learning: Explorative Research Action Study applied to Peer-to-Peer Energy Trading

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**Abstract**—Open science become a mandatory in most funding program. However, literature review on technical domain where algorithms and programs are the core of the contribution show it remains not shared. This article aims to present an instructional module that aims to both sensitize students to research and allow them to participate to research community and open science through replication. This module was implemented two years in a row with computer engineering students. The implementation of the module has been done according to the research action approach, meaning the authors was also involved in the course as a teacher. The course was oriented towards exploring the different peer-to-peer energy trading algorithms. This article describes the pedagogical methods used in class and discuss challenges for adoption of this method more broadly.

**Keywords**—open science, pedagogical engineering, peer to peer energy trading

## I. INTRODUCTION

“Open science” is an umbrella term used to refer to the concepts of openness, transparency, rigor, reproducibility, replicability, and accumulation of knowledge, all of which are considered fundamental features of the scientific endeavor [1]. According to [2], open science consists in the sharing of knowledge, data and tools as early as possible in the Research and Innovation (R&I) process, in open collaboration with all relevant knowledge actors, including academia, industry, public authorities, end users, citizens and society at large. This definition is presented by the European Commission in the context of the Horizon Europe funding campaign.

Open science is a movement that argues the way science should actually be produced. It aims to enhance the reproducibility of and accessibility to research findings by publicly exposing the scientific process by which they were obtained [3]. This concept of open science covers various aspects. From a policy perspective, Open science is considered as a way to improve the quality, efficiency and responsiveness of research.

Although public funding programs such as Horizon Europe are adding rights and obligations to make new projects compliant with open science principles, it remains an important part of the produced knowledge that remains poorly replicable. It is notably the case of scientific production in the domain of peer to peer energy sharing. Few articles from the last years are sharing the data that were used to build the algorithm and even less are providing the code source of the algorithm. Since most of these articles are using

different data set, it is difficult to identify the benefits of one algorithm from another.

The funding programs are good levers to make researchers change their way to do science, but it is also important to sensitize students or young researchers that potentially will be part of the research and innovation department to contribute to open science. One possibility is to introduce open science practices during the curriculum while raising awareness of research practices. One pedagogical approach in particular caught the attention of the authors: research-based learning. This approach allows students to experiment different aspects of research practices according to various degrees of autonomy on each research skills [4]. This approach has led to an improvement in the ability to provide meaningful support to community-based projects and foster critical thinking through real experience [5].

Building on the research-based learning approach, the authors have designed a pedagogical module that confronts students with the limits of current scientific knowledge and production methods, and allows them to contribute by developing programs that are intended to be shared. This article presents how this module was structured and how it was perceived by students. This work adopted a research action methodology to implement this module and observe students.

The next section will present related works about replicability of science and open science education. The third section will present the method applied for this article before providing the data analysis in the fourth section. Finally, the fifth section will conclude about the potential of this approach and some insights about applying it with a larger number of participants.

## II. RELATED WORK

The concept of peer-to-peer energy trading and microgrid are topics of increasing interest in the literature. Number of articles that use the keywords “peer-to-peer energy trading” in their title increased from 911 articles in 2011 to 3134 in 2022 on ScienceDirect. However, authors did not find articles aiming to compare different algorithms in the perspective to identify the most adapted to a context and support the decision-making process except [6]. This maybe since most of the article did not share their data or their algorithm implementation. This makes the replicability more difficult.

The first subsection will present the concept of research-based learning that is the core principle of the article. The second subsection tackle the link between open science and

replicability. This replication difficulty leads the authors to think about crowdsource this replication to students while raising awareness about open science.

### A. Research-based Learning

Research-based learning is one of the education paradigms that focus education on the solution of real problems [5]. The interest of research-based learning resides in the process and involves the active participation of students to gain reflective knowledge and critical thinking to build their vision [5]. RBL students know about the problem, because the teacher provides the information as a starting point and expect the students' thinking and skills to grow through the enquiry process [5]. The role of the teachers is to coordinate and facilitate [5] however the implementation of research-based learning depends on how it is understood and what teachers think research is [7]. Still, research-based learning assumes the students can be engaged in research and inquiry right from the start of their degree [4]. It starts with recognizing the interests and capabilities of students [4] and go beyond the hierarchical idea of research, believing that existing disciplinary content must be learnt before engaging in research [7].

### B. Open Science & Replicability

The reproducibility and replicability are fundamental requirements of scientific studies. [8]. However, the definition of the two terms may differ according to the research domain [8]. For this reason, [8] suggests a visual tool to help the process of definition of replicability and reproducibility by providing a standardized visual tool. For example, they considered reproducibility as some form of formal statistical evaluation to compare estimates of replication and the resulting claims, as shown by the sign of approximation [8]. Although it is fundamental, valorizing replication as an article might not worth it as direct replication is not typically valued by top journals [9].

Domains such social, behavioral, and biomedical sciences are facing a replicability crisis due to an alarming failure rate of experiment that do not obtain the original results [10]. This has an impact on the scientific credibility [10]. This time reproducibility means obtaining the same numerical results when repeating the analysis using the original data and the same computer code [10]. On the other side, replication is the repetition of an experimental procedure in order to produce the same result as the original procedure [10]. This reproducibility crisis is not limited to the above-mentioned domain, it is also the case in computer science domains such as AI field although the experiments are more straightforward to document [11].

Open science is a part of the answer to this crisis as it involves sharing data, software, and other science resources in public repositories using permissive licenses [11]. Aside the fact that research resources have to be open, they also have to adhere to the FAIR principle (findable, accessible, interoperable and repeatable) to allow repeatability, reproducibility, and reuse [12].

### C. Raise awareness about Open Science

There are various institutions that provide instructional materials to raise awareness of PhD students, young researchers and seniors' researches such as the Passport for Open Science for PhD student [13], the DoRANum [14] digital learning material, the recommendations from the

French science academy [15] and many others. A limitation of these materials is it requires some promotion to the targeted readers to have an impact. Furthermore, these documents educate readers on the topics but do not develop their skills. A complementary strategy to develop skills would be to create pedagogical activities for master and PhD students that sensitize them to the challenges and best practices. This sensitization might be done at the same time they contribute to the community by replicate research. The insight to make replication an explicit part of pedagogy has been presented in [9]. However, few articles have been found to talk about promoting or even contributing to open science in a teaching context.

## III. METHOD

The instructional module has been implemented in two consecutive years in an iterative way: 2021 and 2022. Due to health policy implemented at that time, the 2021 session was fully remote meaning all the participants were at home while 2022 session was in person. The first session was further a non-structured experimentation that was first design to make the instruction more active for students and avoid the bad student experience of video conferencing lecture course. Due to positive feedback, the authors decided to reproduce the approach in the 2022 session with further formalization and indicators.

### A. Research Question & Hypothesis

The objective of the article is to evaluate the interest of this module regarding students. As this approach takes place in a curriculum, it must have interest from instructional perspective as well as represent a contribution to the research community. This leads to six aspects that will be observed by the end of the module:

- The approach permits to contribute to open science community
- This approach permits to the students to discover research activities and potential new professional perspectives
- This approach permits for students to learn new software development skills
- This approach permits for students to practice their software development skills to make specific knowledge more accessible
- This approach is positively perceived by students
- This project-based approach permits to understand the concept tackled by the module

### B. Research methods

A common methodology used to study innovation process and educational improvement is the action research methodology [16, 17]. The principle of the action research is to engage in reflection on their action and develop knowledge that helps to regulate those actions in the future [17]. It is a continuous learning process where researchers can take part in the action and collaborate with participants [17]. The common process of action research is composed of planning, acting, observing, and reflecting steps [18].

There are two different data collection methods common in qualitative and action research: observational and non-observational [18]. Among the non-observational data collection methods, the authors kept the survey and focus group method.

TABLE I. SELECTED ARTICLES FOR REPLICATION

Ref.	Session	Title	Architecture	Documentation	Technic
[21]	2021	Peer-to-peer energy trading among smart homes	Centralized	Pseudo code	Optimization
[23]	2021	iDES: Incentive-Driven Distributed Energy Sharing in Sustainable Microgrids	Distributed	Pseudo code	Optimization
[25]	2021	Peer-to-peer home energy management incorporating hydrogen storage system and solar generating units	Distributed	/	Optimization
[27]	2022	Incentivizing distributed energy trading among prosumers: A general Nash bargaining approach	Distributed	flowchart	Game theory
[29]	2022	Demand response-based peer-to-peer energy trading among the prosumers and consumers	Centralized	flowchart	Optimization (BPSO)

### C. Experiments

The two sessions 2021 and 2022 were conducted with computer science engineering students as part of their data science specialization during the 4th year of their cursus. This means that the level of the students is equivalent to first year of master. This module was introduced as a course about smart cities with an emphasis on smart grids as one of the specific developments in the energy dimension of cities. The 2021 session involved 7 students while the 2022 session involved 6 students. The researchers do not have the possibility to select the profile of the students in computer science, nor their number. The hourly volume of the module and the distribution of hours is also imposed for administrative constraints. The challenge of this action research is therefore to initiate a process to observe its effects.

At the beginning of the course, lecture course was given to present the objectives of the course, the evaluation modalities and the schedule of the different sessions. This module was clearly presented as a research-based learning course where they will apply their technical skill to replicate peer to peer energy sharing algorithms found in the literature. As suggested by [9], the central focus was on the replication of the research. In this perspective, the first constraint was to reproduce the article using Python language to do the data processing and calculation with the adapted libraries and documenting it with Markdown documents. The second constraint was to use GitHub to share their code with the instructors and make it accessible online. Github is a popular code sharing web services with version control system and social network features such as bookmarking and “watching”. The articles that were replicated were selected in advance by the authors according to the quantity of information provided by the article (notably flowchart or pseudo-code), the presumed simplicity to reproduce it, the technic used to solve the energy allocation and the architecture adopted that can be centralized or distributed. The Table I present the list of articles that have been selected for this work. The students formed groups of 2 or 3 and they get assigned to one article.

The module last 20 hours in person. The first two hours were dedicated to the presentation of the smart grid and peer to peer energy trading concepts. Then lectures were structured into 6 sprints lasting either 2 or 4 hours. The idea was to adapt the Scrum method to the class session in order to accelerate the production of artefacts. The sprint is a container that include other events and that aims to enable transparency among the team and adapt to issue more easily with short iteration [19]. Students were free to work at home to enrich their contribution between 2 sprints. These sprints started with a short recall of the objective of the sprint and 15

minutes before the end of the sprint, each group presented their progress and their difficulties. During the sprint, students still had the possibility to ask helps to other groups or the professor. The module was concluded a session of presentations and a session of feedback. Each group had 15 minutes to present their work followed by questions. To highlight the objective of making the program accessible to the community, the instruction was to present their work using the documentation of their code and not using presentation program. The last part of the module was a feedback session split into two steps:

- 15 minutes for an online survey.
- 45 minutes for a discussion between students and professor to collect elements that were potentially not covered in the survey.

The Fig. 1 illustrates the timeline of the module.

## IV. FINDINGS

### A. Collected data

Two types of data were collected by the end of this module:

- source code with its documentation through GitHub
- a survey combining open-ended and closed-ended question (Appendix I).

The Table II lists the links to the code produced by students for each article. Concerning the survey, it was only applied during the 2022 session and was specifically designed to observe the 6 aspects mentioned previously. This survey and the data generated is available online with the learning material on Open Science Framework [20].

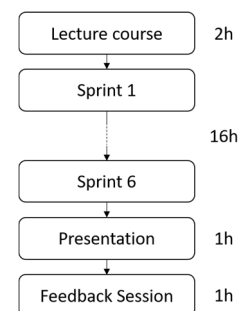


Fig. 1. Structure of the educational module

TABLE II. LINK TO THE CODE PRODUCED WITH THE CORRESPONDING ARTICLE

Ref.	Session	Source code link
[21]	2021	[22]
[23]	2021	[24]
[25]	2021	[26] offline
[27]	2022	[28]
[29]	2022	[30]

### B. Analysis of Collected Data

The analysis of the data collected will follow the six hypotheses presented previously.

#### 1) Contribute to Open Science Community

Among the five articles that have been selected, five were objects of software development and result in five repositories. However, none of them really succeed to entirely replicate the original article. Furthermore, among the three articles replicated in 2021, one repository has been deleted by its owner. For those which stay available online, after one year, none was modified. Moreover, none has been either “forked” or watched on GitHub outside people who participated in the module. It means the contribution to the open science community is inexistent.

#### 2) Discover a New Perspective of Research Activities

This aspect was evaluated through four questions related to previous experience with research activities as well as auto evaluation of learning. All the students of the 2022 session already had experience with scientific literature. Most of them declared they already read between 6 and 10 scientific journal articles during their curriculum. Only one declared have read fewer than 5 articles and another declared more than 20. Four from six already had participated to research projects notably with small projects or internship with laboratory. Based on this experience, only half of them considered this module allow them to better understand how scientific literature works.

#### 3) Learn New Software Development Skills

As this module is part of the computer science curriculum, five questions were dedicated to the evaluation of IT learning. The trend was they rather not learned new computer skills. This is confirmed by the fact they were not able to provide a correct definition of game theory nor binary particles swarm optimization which were the two technics of the article.

#### 4) Practice Their Software Development Skills

Although they did not learn a new skill or concept, they rather consider this module allow them to practice their software architecture and data processing skills (with both a mean at 3.6 and a standard deviation of 1.03 and 1.21 respectively.) However, they slightly disagree the module was the opportunity to practice their data visualization skills (mean: 2.6 and standard deviation 1.21).

#### 5) Approach is Positively Perceived by Students

The module was positively perceived by students. They evaluated it as “rather interesting” with a mean 3.16 over 4 and a standard deviation of 0.4. No evaluation was negative. However, from the six participants one declared not willing to choose this module if he will have the choice. From a qualitative perspective, their interest to the module was due to the novelty of the subject (smart grid and peer to peer energy trading) which is not tackled in their curriculum as well as the novelty of the approach. Another reason they found it interesting is the fact it tries to solve concrete problems and represent a challenge for them. The enthusiasm for the approach in this module was also mentioned during the feedback session. Among the 14 students who participated in this programme over the two years, 5 joining the R&D department of a large company in the energy sector.

#### 6) Understand the Concept Tackled by the Module

From the perspective of the subject of the module which is smart grid and peer to peer energy sharing, four students considered they are more comfortable with the subject while two students consider they are neither more nor less comfortable with the subject after the module. To balance this declarative evaluation, the survey asks the students to give a short definition of smart grid and peer-to-peer energy trading. Most of the response to smart grid was incomplete if ever incorrect, one student did not provide a response and only one provide an acceptable definition. Concerning the question of peer to peer energy sharing, every participant provided a response and most of them were correct although partial.

### C. Discussion

Although the motivation was to replicate articles to share the code with the research community, most of the production are not enough qualitative. It can be explained by various factors:

- None of the students had prior skills in optimization, nor game theory. It is a great opportunity for them to learn and experience but the learning curve can be long. This joins the discussion from [5] that also had a problem regarding a lack of prior knowledge.
- The module is only 20 hours and is an option in the curriculum meaning the impact of this module on the degree is very low inducing less investment than other modules.

After one year, one of the GitHub repositories has been deleted by the owner and none of them attracted attention none of them have a fork or star. These metrics are commonly used to evaluate popularity however they follow different patterns such as Slow, Moderate, Fast, and Viral Growth [31] that depend on various factors such as technologies, domain, user organization, documentation among others [32, 31] Although it is a common tool for software development and sharing open source project, another platform such as OSF could be more oriented towards research. It still this kind of project requires active promotion to see this metric evolve [32].

Concerning increase their awareness about research activities, they already had experience due to previous projects and internship. Only half of them considered having learned something. A way to bring something to the second half would be to add one hour in the timeline to formally explain the scientific literature and changes provided by open science.

The perception of practicing their different software development skills by students is quite scattered. There are two potential reasons for this. First, as the time was limited and they worked in groups, a repartition of the activity has been observed. It means some students worked on data cleaning and preparation whereas others worked on the main software architecture and algorithm. Another reason would be the article by itself that does provide the context to practice of the software development skills. It was not criteria considered when selecting the articles that will be reproduced. The last reason to the variation in their response is their personal and previous experience on one of these activities that are software architecture, data processing, and data visualization. The three questions about the practice of skills do not provide relevant information.

The enthusiasm concerning the approach adopted during this module was notable both in the survey and during the exchange. They found it quite difficult but also concrete and meaningful. These feedbacks are consistent with the observations of [5]. They found it more realistic than other exercises they had in other lectures as the data provided was not perfect and required preprocessing. The specification from the article was not absolutely clear and required some problem solving.

The last aspect is the main subject of the module which is smart grid and peer-to-peer energy sharing. The feedback of the students are they learnt something new and discovered a new domain where computer science could be applied. It is positive; however, the result of the survey brings some clues they further understand the notion of peer-to-peer energy trading than the smart grid. This can be due to the fact that the concept of the smart grid was presented during the lecture course at the beginning of modules whereas the notion of peer-to-peer energy trading was the core of the article replicated.

## V. CONCLUSION

The original assumption of this work is to consider an educational module as an opportunity to both replicate research work in the perspective of participating in a comparative study and practice technical skills. The replication was based on scientific articles selected in advance by lecturers.

### A. Limitations

The first and most significant limitation of this work is the number of participants in the teaching module. A panel of six students is a very small group to have any statistical insights. This work has to be considered as a preliminary work to a future module with more participants. It was the opportunity to experiment the conditions of the implementation of the module, however, it did not allow for complete success. Program produced by students are most of the time incomplete and does not allow a real replication of the original article they tried to replicate. Furthermore, although documentation was explicitly defined as an evaluation criterion of the module, most of the program produced was poorly documented. This result may be due to the project being too ambitious for the time available. Otherwise, the articles selected was too difficult to replicate them or the students needed a specific training on technical aspects of the article.

Most of the literature quoted in this article about coupling open science and pedagogy comes from the psychological domain could disqualify the foundations of the thoughts but the authors were not able to find a similar approach in engineering domains such as electrical engineering.

At this stage, authors only observed the short-term effects of this action research-based experiment. In the next step, with a better understanding of the new process generates by the researcher acting as teachers, it would be interesting to integrate the modalities to integrate the effects of this process in the medium and long term. For example, during the final feedback session, to our surprise, three students indicated that they were joining the R&D department of a large company in the energy sector. It would therefore be interesting to be able to question them in a few months' time about the contribution of the module they have followed.

### B. Concluding Remarks

Replication is an important part of the scientific process; however, it can be difficult for researchers to dedicate time and valorize it. The authors are convinced replication can be interesting in an educational context and still being valuable for the research community. In the context of this work, they think involving students in the replication process may accelerate time to produce comparative study in the domain of peer-to-peer energy trading that remains mostly not open and incomparable. The difficulty is to create the condition that allows a good replication of the articles in order to save time for the researcher but also enables students to learn something. However, although the replication was incomplete, the development done by the students provide a basement to further development for a comparative study.

### C. Future Work

The most obvious perspective of this work is to find the opportunity to involve more students in a similar module in order to have more representative results. Due to the constraints and allocated time, authors also thought to change the course sequence. On one side, adding one hour of lecture course to present the principle of open science and FAIR principles. On the other side, dedicate four hours to present how the different approach such as multi-agent, constrained optimization, game theory, auction theory and blockchain are technically implemented with Jupyter notebook or Colab notebook. This would potentially reduce the learning curve. However, it will let only 12 hours to students to replicate the articles. It implies some part of the work as to be done outside the class hours and also select simpler articles to replicate.

Another change related to the module would concern the platform used to share the code. GitHub is relevant as a development platform for use, reuse and active involvement, but archives such as Zenodo or OSF might be more relevant for reproducibility [12]. It is also interesting to use these archives from the research point of view as it generates DOI to ease citations. Another interesting experiment would be to publish contributions to some post-publication peer review tools such as PubPeer to associate the code with the article. It would also be a way to involve the original authors in the replication process whether it is through this kind of platform or directly by mail.

Finally, even the produced source code is not qualitative enough to constitute a contribution to the community. These produced programs during these two sessions will be reused and improved internally to compare peer-to-peer energy

sharing strategies based on the same data and the same scenario.

Another alternative would be to totally change the modality of the implementation of this module. Initiative outside the constraints of educational institutions may allow citizen centric approach as living lab that has already been implemented to the energy topic such as [33, 34].

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## Appendix I

2022 session survey applied at the end of the module

### Scientific culture

- Before this module, had you ever read a scientific article?  Yes  No
- Could you estimate how many scientific articles you may have read prior to completing the MOM2 module?  1-5  6-10  11-20  20+
- Have you ever participated in a research activity?  Yes  No
- If so, which one?
- Do you feel that you have learned anything about how the scientific literature works?  Yes  No

### Computer skills

- Do you think you have developed new computer skills? *(open question)*
- Can you briefly explain what game theory or particle swarm optimization (PSO) is? *(open question)*
- Do you think you have practiced the following skills:
- |                       |  |                                       |
|-----------------------|--|---------------------------------------|
| Software architecture | <input type="radio"/> Totally disagree | <input type="radio"/> Rather disagree |
|                       | <input type="radio"/> Rather agree     | <input type="radio"/> Totally agree   |
| Data processing       | <input type="radio"/> Totally disagree | <input type="radio"/> Rather disagree |
|                       | <input type="radio"/> Rather agree     | <input type="radio"/> Totally agree   |
| Data visualisation    | <input type="radio"/> Totally disagree | <input type="radio"/> Rather disagree |
|                       | <input type="radio"/> Rather agree     | <input type="radio"/> Totally agree   |

### Evaluation of the module

- what is your feeling on the course (Smart Grid):
- |  |  |
|--|--|
| <input type="radio"/> Not at all interesting | <input type="radio"/> Not very interesting |
| <input type="radio"/> Rather interesting     | <input type="radio"/> Totally interesting  |
- Why ? *(open question)*
- If you had the opportunity to choose the Smart Grid option again, would you re-enroll?  Yes  No
- Why ? *(open question)*

### Smart Grid

- On Smart Grid issues, at the end of this module, you would say that you are:
- |  |   |
|--|---|
| <input type="radio"/> less comfortable | <input type="radio"/> neither more nor less comfortable |
| <input type="radio"/> more comfortable |   |
- How would you describe the Smart Grid concept? *(open question)*
- How would you describe the concept of P2P energy sharing? *(open question)*